EMERY AND THE EMERY INDUSTRY

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A TECHNICAL STUDY OF MODERN ABRASIVES AND THE DEVELOPMENT OF THE MODERN GRINDING-MACHINE INDUSTRY

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PREFACE

In the growth and development of the machinery industry, the pressure of world competition soon led to a recognition of the accuracy of the proverb "time is money". The value of the work performed by the hand of the industrious workman, formerly so highly appreciated, diminished progressively in proportion as ingenious inventors busied themselves with the replacing of limited human endurance by the tireless force of machinery. It is true that manual labour could not be entirely dispensed with, but the modern workman became more and more the servant of the machinery; and every industry that desired to keep abreast of the times had to fall into line in this respect. The fulfilment of these novel requirements led, in turn, to the establishment of entirely new industries, which have already acquired high rank. When the file and grindstone, which formerly constituted the grinding tools of the machinery industry, proved no longer sufficient for its triumphal progress, urgent need arose for mechanical aids; and this need gave the first stimulus to the establishment of the industry of abrasives and grinding machines which, from small beginnings, developed in

a few decades, under the pressure of circumstances, into a condition of prosperity that has rarely been equalled in the time. Even now there is no standing still; and, indeed, that will be impossible for this new industry so long as the older industries continue to struggle in the world market.

It is the object of the present technical study to bring both the engineer and the layman to a fuller comprehension of this new industry, the development and importance of which are still imperfectly known, even in trade circles.

THE AUTHOR.

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INTRODUCTION

One of the earliest acquirements of prehistoric man was the comprehension of the term "grinding". That this should be so was perfectly natural, because as soon as man began to understand the use and production of tools, and to recognize the difference between a sharp tool and a blunt one, he naturally sought for means by which the requisite sharpness could be imparted to his tools or weapons. Nothing could be more self-evident than to work the stone, intended to serve as a weapon or hatchet, with the aid of another stone. In this way he very soon learned, not merely the importance of the frictional motion stone upon stone, but also which kind of stone produced the proper effect in this treatment. He then gradually learned to appreciate quartz and felspar, and to use the wide-spread sandstone; and the applicability of emery for such purposes was recognized in the earliest ages.

Within historic times we have reliable knowledge of this, the old Greek historians having a good deal to say about the riches of the island of Naxos and its "smyris" (emery), which quickly became known as an excellent material for grinding, in competition with

sandstone; but as it could only be used in the form of grains or powder its employment was merely a restricted one for a long time, sandstone grindstones being used both in the handcrafts and in the industries that subsequently developed from these latter.

It was not until the seventies of the last century, when a method was invented for binding the grains together with a suitable medium and compressing them into moulds under heavy pressure so as to form grindstones, that the sphere of application of emery attained rapid extension.

In proportion as the demand for these grindstones and grinding wheels increased, so also was the method of manufacture improved as the result of experience Before long, moreover, other natural grinding agents became the object of investigation, and attempts were also made to overcome the irregularities present in the native raw materials by making artificial emery and other abrasive materials.

In this way the industry of emery and the abrasive materials in general has now become fairly extensive and of considerable importance to the entire machinery industry, though it is still for many—and probably even the majority—a *terra incognita*, the further exploration of which should certainly be profitable to manufacturers and others, if only from the standpoint of self-interest.

CHAPTER I.

ABRASIVE MATERIALS.

In order to facilitate achieving the purpose mentioned at the close of the Introduction, it will be necessary to consider the various abrasive materials more thoroughly, in order to gain from their properties the information requisite for their appropriate utilization in technical practice. The term "abrasive materials" is capable of wide extension; and, indeed, the Report of the Geological Survey of the United States arranges under this heading the following substances: oilstones, scythe-stones (whetstones), millstone quartz and millstones, grindstones, flint, pumice-stone, kieselguhr and tripoli, crystalline quartz and felspar, granite, corundum and emery, carborundum, steel powder, and artificial corundum. This list, however, may be considerably shortened, when it is considered that only a comparatively small number of the foregoing materials are actually used for grinding.

Thus, only a relatively small proportion of the total production of sandstone is used for making whetstones and grindstones, the chief purpose of this stone being for building. The same applies also to oilstones and scythe-stones; whilst millstones are generally used for other purposes, namely, grinding corn. On the other hand pumice-stone must certainly be classed as an abrasive material, this being its sole use, in one form or another. Crystalline quartz and felspar, on the con-

trary, are imperfectly adapted for such purposes; whereas emery and corundum again must be regarded as abrasive materials par excellence, as also the granites that are not used for decorative purposes.

A more satisfactory classification of these materials is obtained by arranging them in accordance with their nature, a distinction being drawn from the outset between the two main groups: natural and artificial abrasive materials.

1. Natural Abrasive Materials.

The natural abrasive materials are more numerous than the artificial ones, and may be divided, according to their nature, into three classes:—

1. The purely siliceous materials, consisting of pure silica, free from any other compounds. This class necessarily includes the whole of the quartz family. The members of this family exhibit a degree of hardness corresponding to No. 7 of Moh's scale, and comprise:—

(*a*) Ordinary quartz gangue, crushed and pulverized, used for polishing timber and stone.

(*b*) Quartz sands, which are used for the same purpose and occur chiefly in the eocene and oligocene beds of the older Tertiary formation, the so-called Bassin de Paris.

(*c*) Sandstone that can be reduced to fine dust by the blows of a hammer, thus furnishing an admirable abrasive material.

(*d*) Siliceous earths, which are abundantly found in calcareous strata.

(*e*) Millstone, originating in the decalcification zone of siliceous limestone deposits and used for grinding in corn mills. (In France, the fresh-water quartzites of the Paris basin are preferably used for this purpose.)

(*f*) Tripoli, a kind of kieselguhr, named after the town of Tripoli from whence it was first obtained.

2. The mixed siliceous abrasives, consisting of silicates in admixture with various bases. The chief member of this group is pumice-stone, a product resulting from the solidification of volcanic masses; another being almadin, or ferrous-oxide granite, frequently met with in crystalline strata. These granite-bearing sands are still won, especially in Spain at Hoyazo near Cap de Gaeta, and also in Brittany. The hardness of granite varies between 6·7 and 7·5. Granite paper is mainly used in the shoemaking industry.

3. The aluminous abrasives, the active constituent of which is pure alumina. The chief representatives of the group is emery.

(*A*) *Emery.*

Emery, which was known to the ancients as an abrasive, and was termed "smyris" by the Greeks (from whence its German name, "Schmirgel," is derived), is an iron-grey, to brown, and generally striated rock, mainly consisting of an aggregation of corundum (Al_2O_3), together with iron oxides (magnetite and hematite).

Dr. Weinschenk, in his work on the "Principles of Geology," rightly characterizes emery as one of the most puzzling of rocks, which may be described as unstratified to shaly, mostly very fine-grained, dark brownish-grey to nearly black, of great hardness and toughness. It is frequently intersected by bluish veins of a granular corundum, which, in a fine-grained condition, constitutes about 50 per cent of the total mass. The other chief constituents discernible under the microscope are margarite and magnetite, as well as chloritoid; spinel and all kinds of aluminous minerals being also found,

in addition to rutile and, characteristically, tourmaline. In Naxos, emery occurs as irregular masses and lodes in granular limestone, whilst in Massachusetts it is associated with micaceous schist. It has also, though incorrectly, been regarded as metamorphic bauxite. It occurs, moreover, in Asia Minor, where it is known as "Anatolian emery"; whilst the emery found at Wildenreuth in the Upper Pfalz district, occurs in eclogites, which are rocks of highly variable character, derived from granitic amphibolites, and, where rich in granite, assume the character of true granite cliffs, which are known as "Smirgel" in the district in question. The so-called Indian emery consists of granite granules or granulations from the precious-stone alluvials of Ceylon.

The best emery is that obtained from Naxos, where the extensive deposits, which were known also to the ancients, are lenticular and range from 16 to 160 ft. in thickness in the saccharoidal limestone. The specific gravity of samples taken in various places ranges from 3·64 to 4·07. In addition to its normal constituents, emery frequently contains varying quantities of tourmaline, disthene, staurotides, rutile, etc. The rock is simply quarried, being detached in large blocks for shipment, these blocks being crushed by the emery manufacturers in stonebreakers which are often of great size. Thus the giant stonebreaker of the Naxos Union Works measures 12 inches by 28 inches across the mouth, the weight being 13 tons, whilst the two chilled-steel jaws weigh no less than 26 cwt. This machine can easily break blocks weighing 2 to 2½ cwt. into lumps as large as the fist (2 to 4 lb.), and can crush 30 tons of crude emery in about ten hours. The lumps from this large breaker pass to smaller breakers, in which they are reduced to the various commercial sizes of

grain, thirty-three in number. The coarse grains are separated from the finer grades by a well-arranged system of screens, the dust left by the crushing and screening processes being afterwards levigated and converted into the various grades of emery powder used for polishing metals, glass, marble, granite, etc. Fig. 1 illustrates a breaker of this kind, as used by

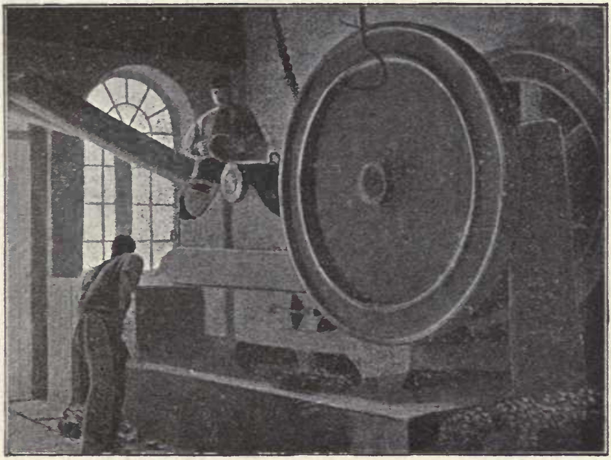

FIG. 1.—Emery Breaker.

the Vereinigte Schmirgel & Maschinenfabriken, Hainholz, Hanover.

It is evident that the grinding action of these composite rocks is entirely due to their content of corundum, which is of the ninth degree of hardness, and is approached in this respect by tourmaline alone (hardness 7·5); consequently the useful effect of an emery disc may be directly regarded as a function of the corundum it contains.

The two subjoined analyses of Naxos emery, both specimens being very rich in corundum, are by Tschermak:—

	Kremno Emery.	Tenidi Emery.
SiO_2 . . .	5·64	5·45
B_2O_3 . . .	1·15	0·88
Al_2O_3 . . .	57·67	56·52
Fe_2O_3 . . .	33·36	34·65
MgO . . .	0·83	0·43
CaO . . .	0·43	0·90
Na_2O . . .	traces	0·60
K_2O . . .	0·31	0·40
TiO_2 . . .	traces	traces
CO_2 . . .	traces	traces
Loss on calcination	0·70	0·42

The specific gravity of Kremno emery is 3·72, and that of Tenidi emery 3·98. Mineralogically, however, their composition is as follows:—

	Kremno Emery.	Tenidi Emery.
Corundum . . .	52·4	50
Magnetite . . .	32·1	33
Tourmaline . . .	11·5	9
Chloritoid . . .	—	4
Muscovite . . .	2	3
Margarite . . .	2	—
Calcite	—	1

The above percentages of corundum (50 and 52·4 per cent), however, seem very high, the average content in commercial emery varying between 30 and 40 per cent, the price in Paris ranging between 250 and 350 francs (£10 to £14) per ton, according to quality, that is to say percentage of corundum.

With regard to the working of the Naxos emery deposits, the Grecian Government, to whom the deposits belong, put them up for disposal to the highest bidder on 6 April, 1871. As the result of this auction a German, Julius Pfungst, the

founder of the Naxos Union, acquired the sole right of selling the genuine Naxos emery for a long term of years over the whole world. This important monopoly was also previously in the hands of a German firm (at Coblenz), which, however, failed to recognize the value and importance of the article, and consequently made only a small profit.

It is true that the world monopoly was not left for long in the hands of the Naxos Union—which was fully aware of its value, and laid the foundation of an initially flourishing new industry in the vicinity of Frankfurt and Offenbach; for, when the Grecian Government recognized the benefits that German industry and foresight were capable of realizing out of the monopoly, it declined to renew the contract on its expiry during the "eighties".

According to the Naxos Union, Naxos emery gave the following composition on analysis:—

	Per cent.
Alumina	57·69
Ferric oxide	30·87
Silica	6·36
Lime	0·89
Magnesia	0·20
Manganese oxide	traces
Loss on calcination	3·99
	100·00

At present this highly valuable natural treasure is again worked by native labour in the most primitive fashion at Naxos, the annual output being 5000 to 6000 tons.

The price of the crude emery is 106·50 francs (85s.) per ton, free quay Syra (on a neighbouring island), whilst the cost of production at the mines is only 52·20 francs (42s. 6d). The appreciable net profit resulting from the difference

enabled the Grecian Government to write off about 300,000 francs (£12,000) from the public debt, from the output in 1903 alone (about 5800 tons).

Almost simultaneously with the rescission of the German monopoly by the Grecian Government, offers of emery were made from Asia Minor, where there are quarries of this material in the vicinity of Smyrna. The production at this centre is about 17,000 to 20,000 tons, but the quality is considered far inferior to Naxos emery, and the sale price in Smyrna is only 70 to 100 francs (56s. to 80s.). Figs. 2 and 3 illustrate one of these emery quarries in Asia Minor, and the method of conveying the emery to the Anatolian railway.

Emery is also produced in the United States, especially at the Peeks Hill quarries in New York State, and at the Chester mines, Massachussets. The output which had increased to about 4000 tons per annum at the commencement of the present century, has since declined, as shown in the following table :—

PRODUCTION OF CORUNDUM AND EMERY IN THE UNITED STATES, FROM 1881 TO 1906.

Year.	Quantity (short tons).	Value. $	Year.	Quantity (short tons).	Value. $
1881	500	80·000	1894	1495	95·936
1882	500	80·000	1895	2102	106·256
1883	550	100·000	1896	2120	113·246
1884	600	108·000	1897	2165	106·574
1885	600	108·000	1898	4064	275·064
1886	645	116·190	1899	4900	150·600
1887	600	108·000	1900	4305	102·715
1888	589	91·620	1901	4305	146·040
1889	2245	105·567	1902	4251	104·605
1890	1970	89·395	1903	2542	64·102
1891	2247	90·230	1904	1916	56·985
1892	1771	181·300	1905	2126	61·464
1893	1713	142·325	1906	1160	44·310

This reduction in the output of American emery, which is particularly rich in pure corundum, is mainly due to the depressed condition of the market, the imports into the United

FIG. 2.—Emery Quarry in Asia Minor.

States of Turkish and Naxos emery having risen, in consequence of the low price, to about 12,000 tons as per the following table :—

Imports of Emery and Corundum into the United States, from 1901 to 1906.

Year ending.	Crushed. Quantity lb.	Crushed. Value. $	Rough. Weight (long tons).	Rough. Value. $	Other Emery Products. $	Total Value. $
1901	1,086,729	43,217	12,441	240,856	10,926	294,999
1902	1,665,737	49,107	7,157	151,959	13,776	214,842
1903	3,505,239	109,272	10,884	194,468[1]	17,829	321,569
1904	2,281,193	109,772	7,054	138,931[2]	11,721	260,424
1905	3,209,915	143,729	11,073	185,689	18,007	347,425
1906	4,655,668	215,357	13,841	286,386	19,339	521,082

(*B*) *Corundum.*

In addition to Naxos emery, which, however, can only be regarded, mineralogically, as an impure form of corundum, the numerous varieties of pure corundum are important in the manufacture of artificial grinding wheels, in which corundum forms a highly valued adjunct for increasing the grinding power.

The density of pure corundum is about 4; and its value as an abrading material depends mainly on whether the sharp, angular edge of the grains has been preserved. This is, however, particularly the case when the grains present fission surfaces, the worn apices being then replaced by a series of cutting edges. Corundum, however, does not present fission surfaces, but surfaces of separation, which act quite automatically.

Nevertheless, this property does not appear with equal efficacy in all corundum deposits, these surfaces being occasionally so numerous that, as for instance with the white corundum from Georgia, the mass falls completely to powder when crushed.

Different varieties also behave very divergently under the

[1] Including emery-stone, value, $5488.

[2] Including emery-stone, value, $7338.

influence of heat. Most of them are suitable for the manufacture of so-called ceramic grindstones, provided the ferric oxide and silicates present can be sufficiently eliminated.

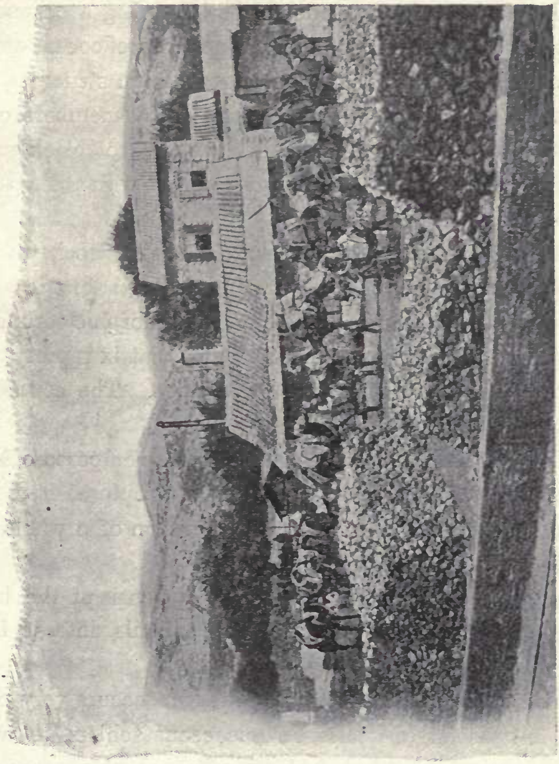

FIG. 3.—Conveying Emery to the Anatolian Railway.

With regard to the occurrence of corundum, the deposits are found in four different formations :—

1. In the eruptive rocks, in which two chief forms occur, namely :—

(*a*) In the form of syenites with corundum. This rock is met with in the Ural district, as large lodes or beds in gneiss, granite, or syenite. The corundum is in the form of large blue crystals, up to 4 inches in length and nearly ½ an inch across, embedded in orthofelspar, the formation being a corundum pegmatite, containing up to 35 or 40 per cent of corundum.

Other rocks are also known, with granolithic structure and composed of corundum and orthomicrogeolithic members, often accompanied with larger or smaller amounts of black mica. These form the so-called corundum syenites, with about 18·50 per cent of corundum.

(*b*) The corundum anorthosites. A craggy rock, locally known as "kyschtymite," occurs in the Ural district, and consists of a granular mixture of small metamorphic corundum crystals, about 1 inch long, and a greyish matrix representing an ortho rock with plates of biotitic mica. The corundum content is 47·5 per cent.

In California, too, there is found a rock, composed of corundum and oligoclase felspar. This is "plumasite," and contains 16 per cent of corundum in the form of crystals not exceeding 2 inches in length.

2. In strata resulting from the metamorphosis of the basic eruptive rocks. This occurrence is of particular interest from the standpoint of petrography.

3. In the crystalline shales. Corundum occurs very often in this formation: in gneiss, in micaceous schists, in white cipoline marble (streaked with grey); and also associated with disthene micaceous schists in various proportions. Blocks weighing up to about 14 cwt. are found in Connecticut. In Burma and Ceylon it forms the extremely rare ruby and sapphire.

4. In alluvial sediments. This occurrence is derived from the previous one. Here the corundum is encountered in a concentrated form, owing to its high specific gravity, in folds and pockets, and in an almost intact condition on account of its great hardness and power of resisting chemical agencies.

So far as the corundum industry is concerned, Canada is the chief centre of interest, as possessing corundum deposits of the greatest economic value; and Canada is therefore the country whose methods of treating the won material should be studied, the industry being comparatively young, and the works equipped with the newest and most perfect machinery and appliances for treating the product.

The best-known corundum deposits are in the eastern portion of the province of Ontario, on the northern shore of Lake Ontario. These deposits appear in three different layers, of which the most northerly is the chief, covering an area about 70 miles long by 2 miles in width, in the districts of Haliburton and Hastings. The corundum rocks are syenites or nepheline syenites. The transition from one formation to the other occurs either imperceptibly, or else through an intermediate stage of barren nepheline syenites, the appearance of which is of interest in connexion with estimating the workability of the deposits, since, in general, the quantity of corundum present in the rock is proportional with the amount of the nepheline rock.

The deposits in Hastings country are worked by the Canada Corundum Co., Limited. The rock which is being worked there is a syenite, with 15 per cent. of corundum, accompanied by a microclinic limestone, sodium-felspar, and magnetite. It frequently happens that the rock assumes the appearance of a pegmatite with extremely large portions of felspar, in which

the corundum crystals occur as globular aggregations of $\frac{1}{8}$ to $\frac{1}{4}$ cubic inch.

The several lodes follow each other at intervals of a few thousand yards, the thickness being about 330 feet. The deposit at York branch, which has now been proved over a length of nearly 1700 yards, is 250 to 330 feet thick. The portion that is being worked at present is a lode running east and west, and situated on the side of a hill about 1650 yards long and 390 feet high. The work is carried on by open-cast quarrying, in terraces measuring 65 feet from front to back horizontally, and 60 feet in vertical height. The rock is blasted with dynamite, and run down to the works on small trucks.

There it is thrown into a hopper holding 450 tons, and falls down into a breaker, the jaws of which measure $24 \times 13\frac{1}{2}$ inches, from which it passes to three other breakers with jaws $9 \times 13\frac{1}{2}$ inches. The fragments, which are now about $\frac{1}{4}$ cubic inch in dimensions, are next passed between six pairs of rollers, then through two sets of drum-sieves of $\frac{1}{8}$-inch mesh, under which are 16 Wilfley concentrators for treating the finest portions, and also 3 jig-screens through which the coarser grains are passed.

Next follows drying by steam and passing through the magnetic separators, after which the grains are classified into 20 grades by means of sieves ranging in mesh from 8 to 200. The final product should now contain not more than 2 per cent of impurities; and if this proportion be exceeded, the material is passed again over the concentrator and pneumatic Hooper jigs.

The daily output is up to 20 tons. The finished corundum is packed in 1-cwt. bags and is dispatched, in the first place by ship, and then on the Canadian Atlantic Railway, to Montreal or the United States.

The production of corundum in Canada of late years is shown in the following table:—

PRODUCTION OF CORUNDUM IN CANADA, FROM 1901 TO 1906.

Year.	Quantity (short tons).	Value. $
1901	434	47·740
1902	805	88·616
1903	916	92·940
1904	919	101·050
1905	1644	149·153
1906	2274	204·973

For technical purposes, corundum is chiefly used as an abrasive material in the form of grains, paper, or grinding discs. Corundum grinding discs are required to possess high resistance and cutting power, the latter being specially important, because on it depends the amount of work that can be turned out by the operator using the disc.

Usually, however, the corundum is mixed with a binding medium, which enables the grinding discs to be moulded. After being sufficiently pressed, the discs are exposed to the heat of a furnace, according to the temperature of which the grinding discs may be divided into two classes:

1. Discs of the older type of manufacture, in which the temperature did not exceed 400° C. For these, the binding medium consisted of rubber, gum lac, magnesia, cement, or a silicate.

2. Discs made according to the new system, in which a temperature above 400° C. is used.

These latter are the so-called ceramic or vitrified discs. The binding medium is kaolin, which is incorporated with the grains of corundum pressed into moulds and dried in an oven, after which the discs are fired at high temperatures in special kilns.

The superior quality of this second type of disc is due to the grains of corundum being partially isolated in the clay matrix, so that they act like small milling cutters, whilst the medium is converted into dust on coming in contact with the work.

Natural corundum is also used in the jewellery industry, in the form of rubies, sapphires, etc.

Attempts have been made to produce aluminium from corundum in the electric furnace; but the material is too expensive for that purpose, although the substance now employed, namely bauxite, has to be put through a preparatory and purifying treatment. On the other hand, endeavours have long been in progress in order to produce a fireproof or ceramic material from corundum.

The output of corundum in the United States has been included in the figures for emery on an earlier page. According to the "Engineering and Mining Journal," the actual production of corundum in 1897 was 293 tons, and in the following year 786 tons.

2. The Artificial Abrasives.

Apart from the foregoing natural abrasives, there is a whole series of artificial products of similar character, among which a highly important position is filled by carborundum. The production of these artificial abrasives is increasing from year to year, as the following table will show:—

Production of Artificial Abrasives in the United States, 1901-1905.

	1902. lb.	1903. lb.	1904. lb.	1905. lb.	1906. lb.
Carborundum	3,741,500	4,759.890	7,060,380	5,596,000	6,225,300
Steel . .	735,000	755,000	790,000	612,000	837,000
Alundum .	—	—	4,020,000	3,612,000	4,712,000

(*A*) *Carborundum.*

Carborundum is a chemical compound of carbon and alumina (the crystalline form of which latter is corundum), and received its name—a condensation of the two components—from Acheson, though scientifically it should be termed silicon carbide, the formula heing SiC.

Although Acheson must be considered the actual discoverer of this compound, its formation had been observed long previously; in the first place by A. Colson, who read a paper on the formation of a new compound of silicon and carbon, before the Académie des Sciences on May 16, 1882 ("Comptes Rendus," 1882, Vol. CIV, p. 1316). This carbide had the formula SiC_2.

Schützenberger, who pursued Colson's research further, prepared a silicon carbide of the formula SiC in 1892 ("Comptes Rendus," 1892, Vol. CXIV, p. 1089). The compound was produced in a small crucible (20-30 c.c.) of retort charcoal, closed by a lid of the same material, and charged with a mixture of powdered crystalline silicon and powdered silica in equal parts. The carbon, however, was not supplied by the material of the crucible, because the carbon crucible was placed in an outer crucible of fireclay and this in turn in a larger crucible, the intervening spaces being packed with lampblack. Consequently, the innermost crucible was not attacked, the silicon carbide being formed by the reducing action of silicon on carbon monoxide at a very high temperature.

Schützenberger, was, therefore, the first to prepare silicon carbide, SiC, in the amorphous form, the crystalline form being afterwards obtained by Acheson in an electric furnace.

Moissan also described the preparation and properties of crystalline silicon carbide, in a paper read before the aforesaid Society on September 25, 1893. The results of his researches in this direction were afterwards recorded in his work on the electric furnace, in which he states :—

"During my experiments on the preparation of crystalline carbon, I had occasion to observe (in 1891) small crystals of silicon carbide in the agglomerations of silicon fused in a carbon shell in the blast furnace. At that time, however, I did not publish anything on this point; so that the priority of the discovery of crystalline silicon carbide remains with Acheson.

"The investigation of the action of the electric arc on silicon led us then to prepare silicon carbide in handsome crystals by four different methods, namely :—

"1. By the direct combination of silicon and carbon;

"2. By preparation in the electric furnace (crystallization in molten iron);

"3. By the reduction of silica by carbon, and

"4. By the action of silicon vapour on carbon vapour."

With regard to the properties of this silicon carbide, Moissan expresses himself as follows :—

"Both the crystalline and amorphous forms of silicon carbide are of high stability, and withstand the most energetic reagents. Silicon carbide entirely free from iron is colourless, and its well-developed crystals occasionally exhibit the form of the hexagonal system. They have a powerful influence on polarized light, and produce a beautiful play of colours."

Acheson went beyond the work of his predecessors in this field, by not only producing this carborundum and artificial graphite, but also preparing a series of compounds of silicon,

carbon, and oxygen, which he grouped under the name 'siloricon'—a new and exceedingly fireproof material.

So much for the historical side! Acheson discovered his carborundum in March, 1891, in endeavouring to prepare, from crystalline carbon, a new abrasive material that should be still harder than corundum—which, at that time, was the hardest abrasive known except the diamond.

In order to render the carbon more fusible, he thought it essential to add a body of lower fusing point, and for this purpose mixed clay with the carbon. This mixture was heated in the electric arc; and on cooling down the furnace, a number of small, lustrous blue crystals of very great hardness, were found on the carbon rod serving as one pole and immersed in the mixed charge.

Acheson at once perceived that these crystals were not diamond, but must be a chemical compound of carbon and another element; and he also found the new compound to be an excellent abrasive.

He then tried to prepare it on a larger scale, in a firebrick furnace, measuring about 10 inches by 4 inches, with a carbon rod at each end. This furnace was filled with a mixture of carbon and clay, the carbons being at first short-circuited, and then drawn slowly apart, so that an arc was formed. In these trials, Acheson found the silica of the clay to be important for the entire process, and he repeated his experiment in a new furnace charged with a mixture of pure white sand and carbon. In this way he ascertained that the new substance must be a compound of silicon and carbon, more especially since analysis revealed the following composition:—

	Per cent.
Silicon	64·93
Carbon and oxygen	32·26
Loss on calcination	1·36
Aluminium	0·25
Calcium, aluminium, iron	traces
	99·80

Subsequently an analysis was made in the laboratory of the newly formed Carborundum Company, on a sample of carborundum that had been purified by treatment with hydrochloric acid and caustic soda, followed by heating in a current of oxygen and digestion with hydrofluoric acid, the following result being obtained :—

	Per cent.
Silicon	69·10
Carbon	30·20
Alumina and ferric oxide	0·49
Lime	0·15
	99·94

This analysis, as also another furnishing the proportions: silicon, 69·59, carbon, 30·41 per cent, agreed with the values calculated for the formula SiC, viz. :—

	Per cent.
Silicon	70·30
Carbon	29·70

1. *Acheson's Carborundum Furnace.*

In the specification of his first patent for the preparation of a crystalline compound of carbon and silicon, Acheson described his furnace—the simple construction of which can be gathered from Fig. 4—as follows :—

The walls, C, of the furnace consist of firebricks, and house the carbon electrodes, BB, which are introduced from opposite

sides, and are connected, externally to the furnace, with electric wires leading in turn to a dynamo or other source of electricity.

The furnace is charged with material, M, which surrounds the electrodes and the core. If a graphitic core be used, it should be arranged as shown at E, between the extremities of the electrodes BB.

On passing through this apparatus an electric current, weak at first but afterwards increasing in strength, the mass is

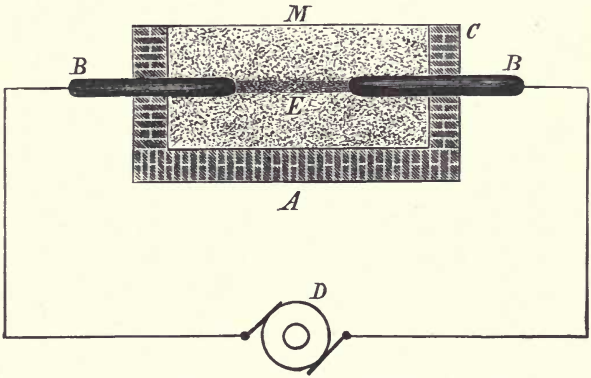

FIG. 4.—Acheson's Carborundum Furnace (Cross Section).

raised to a high temperature, the flux melts, and crystalline carbon products are formed in consequence of the intimate combination of the constituents. During this process chemical combinations and decompositions occur, resulting in the liberation of gases, vapours, and volatile salts, which are allowed to escape from the furnace. There remain, as residue, the following products:—

(*a*) Graphite,
(*b*) Amorphous carbon, and
(*c*) Carborundum,

in addition to an incompletely transformed portion of the charge, exhibiting all stages of the transformation, and adapted to be used over again in recharging the furnace.

The peculiar properties of the crystalline material depend partly on the strength and duration of the current, and partly on the composition and character of the charge.

The inventor employed, in the main, the following proportions by weight :—

	Per cent.
Pure carbon	50
Silica or aluminium silicate	25
Common salt	25

When operations are completed, the products are taken out of the furnace, the carbon material is freed from graphite and other impurities and is broken into small pieces, in order to be boiled, washed, and finally dried by heat, after which it is ready for classifying into crystals of different degrees of fineness.

The crystalline substance is highly lustrous and is usually dark in colour, the shade depending mainly on the class of material used. The crystals are not regular in appearance, but resemble diamond dust, although the octahedral form predominates. Many of these crystals are opaque, some being transparent and colourless, whilst others exhibit a variety of colours. They are extremely hard and refractory; at least they will resist the heat of the oxyhydrogen flame for some time.

When a mixture of carbon, silica, and sodium chloride, in about the foregoing proportions, is employed, the product has the following average composition :—

	Per cent.
Si	69·19
Al_2O_3 Fe_2O_3	0·38
CaO	0·19
MgO	0·06
C	29·71
R	0·47

If, however, a mixture of carbon, clay (aluminium silicate), and sodium chloride be taken in the proportions stated, analysis gives the following result :—

	Per cent.
C	30·09
Si	60·51
Al_2O_3 Fe_2O_3	4·78
CaO	0·17
MgO	0·18
O	4·27

Hence the material known as carborundum must be regarded as a compound of carbon and silicon, the composition of which, when pure, is expressed by the formula SiC.

With regard to the practical application of the material, the patent specification states that, in addition to being an abrasive, it may be used as a substitute for diamond dust (in cutting and polishing precious stones, etc.), and also in the preparation of carbons for electric lighting.

In a Patent of Addition taken out two years later, Acheson modified the process, both in respect of the construction of the electric furnace and of the mixture of materials, whereby an improved product and increased yield were obtained. The principle on which this new furnace (shown as a lateral elevation in Fig. 5 and as a vertical cross section in Fig. 6) was based was that a considerable portion of the current traversed the mixed charge, which ought rather to be influenced, i.e.

heated to conversion point, solely by the heat radiated from the path of the current. For, unless the charge be protected

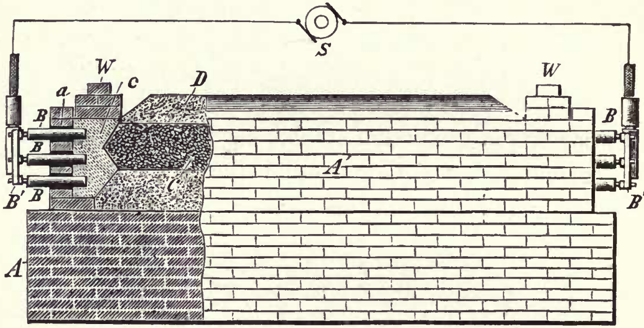

FIG. 5.—Acheson's Second Furnace (Lateral Elevation).

from the passage of the current, the crystalline character of the product is found to be more or less impaired.

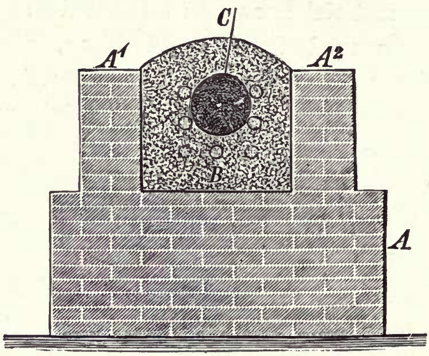

FIG. 6.—Acheson's Second Furnace (Partial Cross Section).

The base A of the furnace is surmounted by a trough of elongated rectangular form, with lateral walls A^1 and end walls A^2. Spaces are left between the bricks of the side walls, so that the gases liberated during the process can escape freely.

Since these gases take fire on issuing from the walls, they assist in heating the furnace and its charge.

The carbon electrodes B, in the form of rods or plates, are embedded in the end walls A^2. According to Figs. 5 and 6, a number of carbon rods are inserted through openings, preferably packed (at *a*) with asbestos. Their outer ends are connected by means of the clamping plate B′, to which the leads from the source of current S are attached.

Furthermore, a single carbon block B— as shown in Figs.

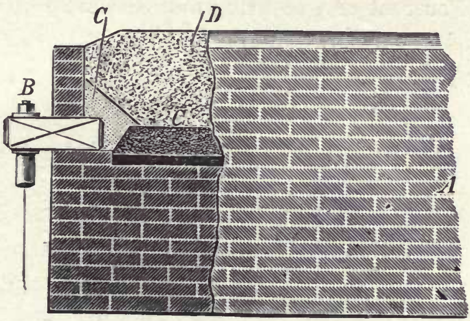

Fig. 7.—Sectional View of Modified Form of Acheson Furnace.

7 and 8—may also be used as electrode, or else several carbon prisms, fastened together in a bundle, may be employed.

Provision must be made for a sufficiently large surface of contact between the inner ends of the electrodes and the adjacent core, and also for the uniform distribution of the current between the various carbon rods.

In starting the furnace, a passage for the core C is arranged in the interior of the charge. This core is of refractory material, which must be of higher electrical conductivity than the materials of the charge.

A very suitable material for the purpose is granular carbon,

the size of the grains varying according to the dimensions of the furnace and the amount of current consumed. Thus, for instance, with a core about 8 feet long, and a maximum energy of 100,000 volts—in which case the diameter of the core should be about 10 inches—the most suitable dimensions for the grains is one-sixth to one-fifth of an inch.

This core—which forms a novel feature of the second patent—is not of uniform shape all the way along, but diminishes towards the ends, an arrangement facilitating the passage of current and ensuring more intimate contact with the electrodes—as shown at C (Figs. 5 and 7), which consists of smaller granules.

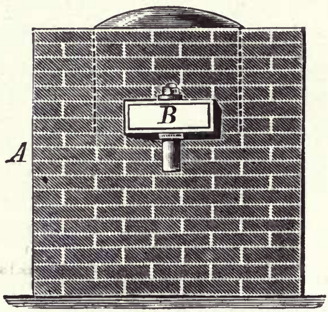

Fig. 8.—End Elevation of Modification of the Acheson Furnace.

To prevent the formation of incrustations on the electrodes, from contact with the material under treatment, the electrodes are allowed to extend into the body of the core (at *c*).

The charge of material D is then arranged round the core.

In order to increase the electrical resistance of the mass, and at the same to make the latter more porous, so that the gases may escape more easily, the charge was made up of the following ingredients:—

	Parts by Weight.
Carbon (coke or the like)	20
Sand	29
Common salt	5
Sawdust or cork	2

This mixture is intimately incorporated and strewn around the whole length of the core. Under these conditions the field in which the crystals are formed is situated in the immediate vicinity of the core, and assumes an annular or cylindrical shape round the mass of the core.

With regard to the capacity of this type of furnace, those at the Niagara Falls plant are constructed for a consumption of 746 kilowatts, and produce about 3 tons of carborundum in thirty-six hours, an output equivalent to 3·8 kilowatts per lb, the intermediate products and the partially unconverted portion of the charge being left out of consideration. If, however, these intermediate products be utilized for the next charge, then the consumption of energy per lb. of carborundum is naturally lower.

2. *Equipment and Operation of Carborundum Works.*

The following description of the equipment and operation of the carborundum works at Niagara Falls is taken from the work on carborundum by Francis A. J. Fitzgerald of the International Graphite Co., Niagara Falls, N.Y.

In the works of the Carborundum Company the materials for the charge, sand, coke, sawdust, and salt, are stored in buildings near the furnace house. The sand is good glass sand, prepared by crushing quartz, followed by washing and drying. It contains 99·5 per cent of silica, the chief impurities being iron and aluminium. The coke is similar to that used in blast furnace work, and is of high, uniform carbon content. The sawdust is used merely to render the mass

porous. Salt is only added in small quantities, and may be of the cheapest quality; it is volatilized and permeates the whole furnace, thus eliminating the impurities, iron, etc., in the form of chlorides.

All these ingredients are stored ready for mixing, except the coke, which is first passed through a breaker, and is then raised by an elevator to the screens for the core material. One of these screens separates the particles that are too small for use in making the core, whilst only those portions that are of the right size for the core traverse the meshes of the second screen. The screenings are then run through a pipe into a mill, where they are ground, after which they are raised by an elevator to the powdered-coke bunker. From this receptacle the powder is drawn off into a barrow, standing on a weighbridge on which the several ingredients of the charge are weighed out. The charge is weighed out in ½-ton lots, which are shot from the barrow into a hopper leading to the mixing drum by way of an elevator.

According to Dammert, the raw materials are preferably of the following composition:—

	Coke.	Sand.	Salt.
C	90·24	—	—
H_2O	0·28	0·01	0·45
SiO_2	5·53	99·55	—
P_2O_5	0·05	—	—
SO_3	—	—	—
Cl	0·01	—	0·64
Fe_2O_3	2·22	0·29	—
Al_2O_3	1·69		
CaO	0·18	0·07	—
MgO	0·06	0·02	0·47
K_2O, Na_2O	0·02	—	—
NaCl	—	—	98·54

The mixture is then compounded of :—

	Per cent.
Sand	57·4
Coke	39·00
Sawdust	11·6
Salt	2·0
	100·00

In his Austrian Patent, No. 42,115 (1894), Acheson gives the ratio of the mixture as :—

	Per cent.
Carbon	40
Sand	40
Common salt or aluminium silicate	20
	100

Since 1892, the furnace plant at the carborundum works consists of fifteen furnaces (each of 746 kilowatts), measuring 23 feet in length outside, the internal dimensions being : length 16½ feet, width 6 feet, height 5½ feet. The side walls are rebuilt for each charge, the end walls, with the electrodes, being left standing. The electrodes are composed of twenty-five carbon rods 33¾ inches long and 4 inches square, built into the end walls in horizontal rows of five each.

On the outside, and between the horizontal rows of carbons, are arranged copper plates 4 inches wide, ½ inch thick and 26 inches long ; the perforated ends of these plates projecting from the carbons, in order that the current leads may be bolted on to the plates.

The diameter of the core in these furnaces is 21 inches.

The electric energy required for the furnaces is furnished by the power station of the Niagara Falls Power Co., the current being of 2200 volts tension, which is reduced to 150 volts by

transformers at the carborundum works. Furthermore, the tension of the secondary current can be varied from 75 to 210 volts, in uniform stages, by means of a regulator arranged between the furnaces and transformers. A unit, consisting of a transformer and a regulator, is provided for each set of five furnaces, but only one furnace is connected up with each unit at any one time. The fusion process takes thirty-six hours. At the start, full tension is available until the consumption of energy by the furnace has attained 746 kilowatts. In proportion as the resistance diminishes, the tension is then lowered, but in such a manner that the consumption of energy remains constant throughout. When the fusion process is completed, the current is shut off at the transformer by opening the primary circuit, whereupon the cables are detached from the furnace and attached to the next one that is ready, an operation that can be performed in five minutes.

The fusion process itself is a highly interesting one, and is described by Fitzgerald as follows:—

"When the carborundum furnace has been running for about twenty minutes, a peculiar smell is noticed, arising from the gases escaping from the furnace as a result of the charring of the sawdust in the mixture. On a light being brought near the furnace walls, the gas, which consists chiefly of carbon monoxide, ignites with a slight explosion. To prevent the poisonous gas from escaping, unconsumed, in such large quantities, it is ignited as soon as possible, though otherwise ignition would ensue spontaneously after a short time.

"In about one to two hours the furnace will be completely enveloped in the burning monoxide, and remains in this condition throughout the rest of the process.

"Meanwhile the mixture, which at first was piled to a height

of over 3 feet above the upper edge of the furnace walls, gradually sinks until, by the time the process is completed, it is only level with or below the edge.

"Sometimes, the phenomenon known as 'blowing' occurs: gases which have formed cavities in the charge, bursting out with great violence and causing a loud howling noise, white hot masses being also projected from the interior of the furnace. These gases burn in the air with a deep yellow, bright flame; but if a piece of cold iron for instance be held in the flame, it immediately becomes coated with a white deposit of silica.

"When the process is at an end, and the current has been turned off, the side walls of the furnace are partially dismantled, and the loose, unconverted mixture is removed. After cooling for several hours, the crust of unconverted charge and the 'white stuff' surrounding the carborundum are also taken away, followed by the upper portion of the cylinder of carborundum, and finally by the lower half of same."

3. *Purification and Properties of Carborundum.*

Since there are always three furnaces in work at the same time, the output in thirty-six hours amounts to nearly $9\frac{1}{2}$ tons, equivalent to a production of about $6\frac{1}{4}$ tons per diem. On its removal from the furnace the carborundum is first crushed in iron mills, and is then transferred to large wooden vats lined with lead, where it is lixivated with concentrated sulphuric acid for several hours, in order to remove various impurities. After this it is washed with water in long wooden vessels, the washings being passed through settling tanks in order to separate the powdered carborundum from the grains, which can then be recovered separately.

The washed and dried carborundum is next passed over a series of grades ranging in size from No. 8 to 220; and in addition to the various grades thus obtained, there are three grades of powder, prepared by levigating the carborundum dust deposited in the settling-tanks.

To make grindstones and grinding discs, the grains of carborundum are mixed with kaolin and felspar, the mixture being moulded under hydraulic pressure, and fired in a kiln resembling a pottery kiln. Caoutchouc and shellac may also be used as binding media for this purpose. Finally, carborundum is also put on the market in the form of carborundum cloth or "paper".

With respect to the properties of carborundum, the specific gravity varies between 3·171 and 3·214. The crystals are rhombohedral.

Ruby, corundum, and sometimes diamonds, are scratched by carborundum, which is placed between 9 and 10 (but nearer the latter) on Moh's scale of hardness.

If carborundum be adulterated with corundum or emery, these admixtures may be detected by placing the sample in a solution (specific gravity 3·5) of methyl iodide in benzol, as they will subside in this liquid, leaving the carborundum in suspension.

Other uses of carborundum comprise refractory material (lining for metallurgical furnaces), to replace ferrosilicon in steel making, and for the preparation of silicon.

4. *Output of Carborundum.*

The following table illustrates the rapid growth in the production of carborundum in the United States.

Output of Carborundum, 1892-1906.

Year.	lb.	Year.	lb.	Year.	lb.	Year.	lb.
1892	1000	1896	1,207,800	1900	2,634,900	1904	7,060,380
1893	13,200	1897	1,256,400	1901	3,838,175	1905	5,596,000
1894	32,200	1898	1,447,200	1902	3,741,500	1906	6,225,300
1895	226,000	1899	1,741,245	1903	4,759,890		

The manufacture of carborundum has also been commenced in Austria, Canada, France, and Germany.

The present price of carborundum is about £32 per ton, *ex* works. Unfortunately, it is too brittle to use alone as an abrasive, and the more promising its economic efficiency at the commencement of working, the sooner it wears away.

(*B*) *Artificial Corundum.*

Artificial corundum has been manufactured uninterruptedly since 1837, though for the most part only for the production of jewellery.

Within the past few years, however, works have been established at Niagara Falls for the preparation of artificial corundum for other purposes as well. Though the manufacturing process is maintained a profound secret, it is known that the process relates to the treatment of Georgia or Arkansas bauxite in the electric furnace, under high temperature and pressure, to imitate the reactions and conditions under which natural corundum was formed. It is also known that great difficulties have been encountered in carrying out the process.

A French Patent has been taken out by W. Werlein, for the preparation of artificial corundum, under the name "diamantite"; and this invention is being tried in Rheinfelden.

Corundum can also be produced from the waste matter from alumino-thermic processes. This corundum is partic-

ularly hard when the raw material is derived from the chromium process, the product containing traces of that substance.

Still another process for the preparation of artificial corundum was made public in May, 1908 ("Mining Journal," 27 June, p. 781). According to this process, 100 parts of pulverized fused borax, 100 parts of aluminium dust, and 125 parts of flowers of sulphur are mixed in a crucible and calcined with a mixture of magnesium and barium dioxide. When cold, the melt is treated with dilute ammonia; and the aluminium hydroxide, formed by the decomposition of the aluminium sulphide, is eliminated by means of hydrochloric acid.

Finally, a residue is obtained which contains globules of aluminium, brown flakes of boron, and a white crystalline powder of corundum. After removing the metallic globules, the boron is dissolved in nitric acid, leaving the pure crystalline alumina, i.e. corundum, behind.

Several German patents have been taken out for making corundum artificially. For instance, the Patent (No. 97408) of Dr. G. Döllner of Rixdorf is for a process of making artificial, fused, or sintered corundum. Powdered aluminium is intimately mixed with oxides, peroxides, or other metallic compounds with oxygen, a characteristic feature of such a mixture being that, when ignited by suitable means, it reacts endothermally, owing to the extremely high combustion temperature of aluminium, and causes the formation of aluminium oxide, accompanied by separation of the metals whose oxides, peroxides, or other oxygen compounds were used.

In this reaction the aluminium oxide is completely fused and solidifies, on cooling, to a mass that is characterized by extreme hardness. The non-metallic components used in this process may consist of nearly any oxygen compound,

though, of course, the temperatures attained in practice will depend on the amount of energy required to decompose the oxygen compound employed. Oxides of the heavy metals are specially adapted for this process.

In addition to the aluminium oxide (corundum), there is formed a metal or metalloid, which may either be eliminated by metallurgical means, or left in a more or less finely divided state in the fused aluminium oxide.

Thus, a mixture of chromium oxide and aluminium furnishes both the alumina and separated chromium in a molten condition, so that on cooling, two strata are obtained: an upper one of aluminium oxide, and a lower one of metallic chromium. If, however, chromium oxide be replaced, for instance, by boric acid, the boron does not separate out, but remains finely divided in aluminium oxide.

The corundum obtained by the above process is so hard that it is able to scratch natural emery, and can replace diamond for any technical purposes. It is, moreover, superior to diamond and silicon carbide in one respect that should not be undervalued, namely that it can be prepared in solid blocks of any desired size, which can be cut into the shape of grindstones equal in durability and efficiency to those produced in any other way. The material is also suitable to replace diamonds in drill crowns; and it should be pointed out that the dulled edges can be sharpened by chipping. It can also be crushed in the same way as emery, and then moulded in the usual manner, with or without a binding medium.

Mention should also be made of a process for converting native emery into anhydrous, iron-free corundum, patented by F. Hasslacher, Frankfurt-on-Main (German Patent 85,021). The inventor bases on the fact that native emery is not pure

corundum, but a mixture of this substance with metallic oxides, especially ferric oxide, of which it may contain as much as 30 per cent. Now the presence of this ferric oxide impairs the abrasive power of the emery considerably; and the latter may be purified in the following manner:—

The native emery is mixed with a quantity of charcoal or powdered coke corresponding to the percentage of ferric oxide, and is then exposed to the arc of an alternating current in an electric furnace. Under this treatment the mass fuses together, the ferric oxide being at the same time reduced, by the carbon, to metallic iron, which melts and runs together in lumps.

Native emery also contains up to 5 per cent of combined water, the presence of which is a source of considerable trouble in the baking of emery discs at high temperatures. This water also is eliminated by the above process, the resulting corundum being not only free from iron but also anhydrous.

A furnace for carrying out this process is shown in Fig. 9. The furnace wall A is made of firebrick and rests on girders H, so as to leave, between the furnace and the flooring, a space B into which the molten emery can run down through the opening D. The two carbon electrodes CC of an alternating electric current project into the interior of the furnace.

The *modus operandi* is as follows:—

The round opening D in the bottom of the furnace is covered with a fusible plate P (of glass for example). The two electrodes are then introduced, and brought to within $1\frac{1}{4}$ to $1\frac{1}{2}$ inches of each other; and the interior of the furnace is charged with emery and powdered carbon, a few lumps of carbon being placed, in order to conduct the current, between the tips of the electrodes. When the current is turned on

these lumps become white hot and cause the emery to melt; and while in contact with the molten emery, are absorbed by and reduce the contained ferric oxide, so that in a very short time an electric arc is set up between the electrodes, its formation being revealed by a buzzing noise.

In a very short time there forms round this arc a mass of molten emery, which is surrounded by a rigid crust on the side next the unmelted material S.

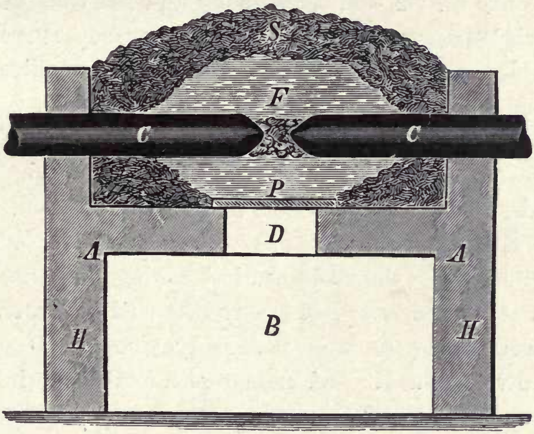

Fig. 9.—Hasslacher's Furnace.

Carbon monoxide gas escapes through the cracks in the furnace walls and the surface of the charge, which gas burns with a blue flame when ignited, and indicates that the reduction of the ferric oxide is in progress.

As soon as the glass plate P fuses, the molten emery runs down, as a stream of brilliant whiteness, into the under chamber B, the floor of which is preferably strewn with ordinary, coarsely powdered emery, in order to protect the firebrick from the extremely high temperature of the mass.

When a fresh quantity of the charge is allowed to descend, by breaking the solid crust with iron bars, the fresh influx of charge cools down the previously molten emery round the opening B, and closes the latter, which does not reopen until the surrounding portion of the charge has fused once more, this occurring at the end of ten to fifteen minutes, so that the process goes on continually.

The solidified product is crystalline, nearly colourless, with a lustre like quartz, and occasionally dull red (ruby) or blue, in which latter event beautiful deep blue, transparent crystals of sapphire will be found agglomerated in small cavities in the mass.

For emery containing about 25 per cent of ferric oxide, an addition of 5 per cent of carbon is required, though, as the electrodes furnish carbon to the mass, 4 per cent will suffice.

The deposited iron contains some aluminium; and this aluminium-iron is then collected in breaking up the melt, and is separated by means of an electro-magnetic separator.

In working on the large scale, a dynamo of 300 amperes and 110 volts is used; and measurements taken during work give an amperage of 250 to 300, with a voltage of 40 to 60 at the terminals.

A suitable raw material for this process is afforded by the dust powder from the emery mills, this material being of low technical value otherwise.

As regards the production of artificial corundum, or alundum, in the United States, the output of the Norton Emery Wheel Co. in 1906 amounted to 4,712,000 lb. (value $ 282,720), and in 1905 to 3,612,000 lb. (value $ 252,840), corresponding to an average price of 5 cents per lb.; whereas in 1904 the production was 4,020,000 lb. Most of the above

output is consumed in the Norton Co's own works, for the preparation of corundum grinding discs.

(*C*) *Crushed Steel.*

Crushed steel is produced in a special factory at Pittsburg U.S., and is chiefly used for cutting up blocks of marble, granite, and other stone. A high grade of crushed steel, known as steel emery, acier émeri, or rouge, is employed for glass-cutting, and costs about 5 cents per lb. at the works.

The following table shows the output of crushed steel in the United States during the past few years. Prices ranged between 5½ and 10 cents per lb. according to quality; and the output in 1905 was largely made up of the higher grades.

PRODUCTION OF CRUSHED STEEL IN THE UNITED STATES, 1898-1905.

Year.	lb.	Year.	lb.
1898	660,000	1903	755,000
1899	675,000	1904	790,000
1900	700,000	1905	612,000
1901	690,000	1906	837,000
1902	735,000		

(*D*) *Electrite.*

In conclusion, mention may be made of another recently invented artificial abrasive, intermediate in properties between carborundum and American artificial corundum. Electrite is uniform in texture and extremely tough, so that it offers very powerful resistance to a crushing force. The grain is sharp-edged, though the structure is amorphous.

The prices of the principal abrasives, in the form of grains per ton, free Paris, are as follows:—

	Francs.	
1. Canadian corundum . . .	700-1000	(£28-£40)
2. Naxos emery . . .	300 - 350	(£12-£14)
3. Turkish emery . . .	250 - 300	(£10-£12)
4. Garnet (rough) . . .	200 - 250	(£8-£10)
5. Lipari pumice . . .	60	(£2 8s.)
6. Tripoli	125	(£5)
7. Rough (crushed steel) . .	90 - 200	(£3 12s.-£8)
8. Carborundum . . .	800-1100	(£32-£44)

The prices at American works in 1905 were :—

9. Canadian corundum . . .	$4\frac{1}{4}$-$5\frac{1}{2}$ cents per lb.
10. Garnet (rough)	$29·32 per ton.
11. Tripoli	$3·01 per ton.
12. Carborundum	7-10 cents per lb.
13. Crushed steel	$5\frac{1}{2}$-11 cents per lb.
14. Alundum (artificial corundum) . .	7 cents per lb.

CHAPTER II.

EMERY AND GRINDING DISCS.

Of all the abrasives mentioned in the previous chapter, emery, corundum and carborundum have attained by far the greatest importance for grinding purposes; and, in fact, our attention may be restricted to the first of these three substances in devoting further consideration to this new and comparatively young industry, because everything that may be said on the development of the emery industry in all its stages, applies, *mutatis mutandis*, to the other two. Emery is used for a great variety of purposes in connexion with grinding and polishing; but its chief uses may perhaps be grouped into the three following classes:—

1. The preparation of emery discs and emery wheels;
2. The further treatment of emery discs;
3. The grinding-machine industry.

1. The Preparation of Emery Discs and Emery Wheels.

The progressive development of German industry, which took its rise in the middle of the nineteenth century, and, after a slow beginning, proceeded to grow with increasing rapidity was accompanied by increased demands on the makers of machinery, to an extent that surpassed by capacity the tools available at the time.

The heavy compulsion of extreme necessity then led to the establishment of an entirely new branch of industry within the extensive general machinery industry, and one that seemed, during succeeding decades, capable of raising the entire machinery industry to a far higher level than before: namely the machine-tool industry. This industry was designed to follow the march of events and keep pace with the growing requirements of the world market, by replacing the limited capabilities of hand labour by machine tools, capable of running day and night without fatigue, and of increasing the output by ten- and even a hundred-fold the quantity previously turned out by even the most industrious workman when using all the forces at his command.

The ever-growing competiton led, *inter alia*, to a demand for good, up-to-date grinding tools, in place of the old, inefficient grindstone or hand file, so as to yield better and, above all, quicker results. It is true that emery was already regarded as the best abrasive known; but it was then chiefly used in the form of grains, whereas the task to be accomplished was to discover another form, more suitable for operating by mechanical means.

The first step in this direction was the production of emery grinding wheels which, in contrast to the natural sandstones previously used, had to be made exclusively by artificial means, and consequently presented a task of considerable difficulty, the requirements to be fulfilled being by no means easy to satisfy. For instance, an emery grinding wheel must

(1) be able to resist completely the action of centrifugal force;

(2) have great durability, in order to compensate for its higher initial cost by greater working efficiency;

(3) be insensitive to atmospheric influences of all kinds, especially damp;

(4) be sufficiently uniform and hard to perform the most divergent tasks placed upon it by the material (cast and wrought iron, steel, bronze, brass, copper, nickel, glass, marble, etc.) to be ground, and the shape of the work (edges, plane surfaces, saw teeth, spirals, etc.) to be treated; and finally,

(5) the binding medium used must be free from all deleterious ingredients capable of affecting the health of the grinder.

(*a*) *The Binding Medium.*

It was in connexion with this factor that the greatest difficulties arose. Naturally, at first, recourse was had to substances that harden like cement; and the earliest emery grindstones were made in this way, by the cold process. This system, however, was highly unfavourable, on account of the great unreliability of the resulting product in use. With discs of this kind, breakage was an ever-present contingency, owing to the faculty of chemical compounds for becoming active under certain conditions after years of quiescence, and thus setting up alterations or stresses in the interior of the discs, the consequence being the formation of cracks, or the splitting and bursting of individual portions. These stones also naturally suffered considerably under atmospheric influences, being, therefore, liable to "weather," and requiring to be stored in the dry.

Moreover, the quality and grinding properties of these wheels was impaired by the practical elimination of the porosity of the emery by the use of similar cementitious binding media, which filled up all the pores; and on this account,

such discs were very liable to slip in contact with the work, instead of exerting a grinding effect, especially when made of fine-grain emery. Their only advantage was cheapness; and they were very well termed "cheap and nasty". Probably the only use to which this class of grinding disc is now applied is for rough grinding; and their practical employment entails the adoption of special precautions, guards, etc.

A better medium was that made with vulcanized rubber. Wheels made in this way had a very high working capacity, especially under heavy pressure and when running hot, the binding medium then burning away. In other respects also they were far more reliable in use than the discs made by the cold process, and would certainly have been able to retain their hold on the market for a longer period, were it not for the adverse influence of various other circumstances.

In the first place, a new binding medium—the so-called ceramic medium—was invented in America; and on the other hand the rapid growth of the motor-car industry led to such a rise in the price of rubber that the vulcanized-rubber grinding discs were no longer able to meet competition. Nevertheless, this rubber medium exhibits the property of high resistance to wear, and usually imparts longevity to the discs, its elasticity, moreover, rendering it peculiarly suitable for use in thin discs. In addition it can be used for grinding various kinds of metal, and also for wet (water or oil) or dry grinding.

Still other forms of binding medium made their appearance, some of which are still successfully used. One of these is the oil medium, equally adapted for wet or dry grinding. Although grinding wheels of this kind appear very delicate, they act with considerable energy, and are particularly suit-

able for sharpening machine knives and saw teeth, in automatic grinding machines, as well as for grinding soft metals and other soft materials.

Greater hardness and durability is exhibited by another kind, namely, grinding wheels made with mineral binding medium, which, though only fit for dry grinding, are excellently adapted for rough grinding and finishing wrought or cast iron and steel. Shellac, glue, rubber, and sulphur have also been used as binding media.

All these methods, however, are far surpassed by the ceramic binding medium, which was first used in America. The binding medium is vitrified with the abrasive at white heat, in pottery kilns, where the goods are fired at the maximum heat of the kiln, and thus retain their cutting properties and reliability in work. In contrast to other binding media, the medium in the grinding wheels, made according to this system, does not diminish the grinding power. On the contrary, the highly porous texture of these wheels greatly increases their utility, so that they can be employed for grinding soft, smeary materials, such as mild steel, brass, red brass, etc., without smearing.

Moreover, the texture of these wheels is unalterable, and they are insensitive to atmospheric influences, cold, heat, or moisture. They do not throw off any dust or smell in use; and, in wet grinding, their porosity causes the water to be absorbed, and consequently given off again, in the form of tiny particles, to the work.

(*b*) *Hardness and Grain.*

The hardness of the binding medium is a very important factor, and expresses the degree of resistance it opposes to the

detachment of the grains of emery. This hardness, of course, has nothing to do with the hardness of the abrasive, the grains of which are embedded in the medium. Emery wheels can be obtained of varying degrees of hardness, according to the kind and quantity of the binding medium used and the degree of pressure applied in the manufacture. This hardness must, of course, be commensurate to the kind of work for which the emery disc is to be used, since, otherwise, it would readily smear, through the collapse of the pores, or it would wear down too quickly. As a rule it may be said that the greater the degree of hardness of the disc, the smaller the amount of wear; but on the other hand, the lower its abrasive capacity.

The degrees of hardness are, unfortunately, arranged by the various makers on different principles, though the introduction of a uniform scale is highly desirable.

A well-defined scale of hardness comprises, for example, all the letters of the alphabet, i.e. twenty-five to twenty-six degrees, as follows:—

Scale of Hardness.

Degree	A	very soft	Degree	N	medium
,,	B	,,	,,	O	,,
,,	C	,,	,,	P	,,
,,	D	,,	,,	Q	medium hard
,,	E	soft	,,	R	,,
,,	F	,,	,,	S	,,
,,	G	,,	,,	T	,,
,,	H	,,	,,	U	hard
,,	I	,,	,,	V	,,
,,	J	medium soft	,,	W	,,
,,	K	,,	,,	X	,,
,,	L	,,	,,	Y	very hard
,,	M	medium	,,	Z	,,

The letters between the terms "medium soft," "medium," etc., indicate regular gradations, so that disc K, for instance, is two degrees softer than "medium," whilst, on the other hand, disc O, for instance, is two degrees harder than "medium," but not quite "medium hard". Other scales are subdivided into a smaller number of degrees; but each maker of these discs supplies five chief grades of hardness: "hard, medium hard, medium, medium soft, and soft".

The class of grain of the abrasive material forming the disc is also of importance with regard to the purpose for which the disc is intended, the size of the grains depending on the hardness of the article to be ground, and on the accuracy or smoothness of the surface to be produced.

The grain, which also governs the roughness of the disc, is classified according to numbers representing the number of meshes per inch of the screening sieve used. The table on p. 48 gives the most suitable degrees of hardness and grain of carborundum discs.

Generally speaking, the finer numbers are used for obtaining delicate, fine finish, and therefore for fine metal work, sharpening knife blades or sharp instruments, etc.; whilst the middle numbers are for finishing off metals, coarse tools, etc.; and the coarse grades for grinding away larger quantities of metal.

(c) *Peripheral Velocity.*

Another point of importance is the peripheral velocity at which the discs are run, alterations in this particular having an extraordinary influence on the result of the grinding, since there is no doubt that the amount of work done by one and the same grinding disc will vary considerably at different

speeds. As a guide, the following considerations should be borne in mind:—

Other conditions being equal, and on the same piece of work, a soft grinding wheel must be run faster than a hard one, in order to prevent excessive wear; whereas, conversely, a hard disc must be run more slowly, so that it may bite better and not cause the work to get hot and the pores of the disc to get smeared. The appearance of these latter phenomena is a sign that the disc is too hard for the work in hand and the actual speed employed. The defects may be obviated by taking a softer disc, or reducing the speed at which the hard disc is run. On the other hand, however, the speed (number of revolutions) of every disc must be increased in proportion as the disc wears down, in order to maintain the right peripheral velocity and full working capacity of the disc as nearly constant as possible.

SUITABLE HARDNESS AND GRAIN OF CARBORUNDUM DISCS FOR VARIOUS CLASSES OF WORK.

Work.	Grain.	Hardness.
Hard steel jaws—		
Outer surface	36-40	O
Inner surface	100	L
Extra hard	80	R
Chill-cast jaws	24	H
Bronze and brass castings	24-36	I
Wrought iron slide valves	40	K
Lathe poppets	100-150	L
Turning and planing steel	30-40	I-J
Turning and planing gun steel	30-36	I
Chill-cast railway wheels	24	G-H
Chill-cast hardened manganese steel	16	H
Cycle frames	30-36	H
Milling cutters	60-80	L
Milling (back cut)	60	O
Swage forgings	24-36	G-I
Screw stocks	60-80	L

SUITAB'E HARDNESS AND GRAIN OF CARBORUNDUM DISCS FOR VARIOUS CLASSES OF WORK.—*Continued.*

Work.	Grain.	Har.lness.
Castings, large	16-24	G-H
Castings, small	29-30	G-H
Castings (facing'	20	R
Castings (finishing)	60-80	H
Chill castings	20-24	H
Chill-steel ba'ls (removing burr) . .	24-30	G
Planing-machine cutters	30-36	O
Wood-milling tools	40-60	M-N
Wood drills	36-40	L-M
Cold chisels	24-36	H-J
Hack saws	40-60	H-I
Mild-steel piston rings (finishing) . .	80	J
Machine parts (general)	20-30	G-H
Metal saws	70-80	G-H
Broaches	60-80	L
Red brass castings	30	H
Malleable castings (heavy)	20-24	H
Malleable castings (light)	24-30	H
Wrought iron (light)	20-30	H
Wrought iron (heavy)	16-24	G-H
Forgings (heavy)	20-24	G
Forgings (light)	30-36	H-J
Forgings, mild steel	24-36	H-J
Twist drills	50	O
Mild steel	24-36	H-J
Hardened steel	40-80	K-M
Very hard steel (facing)	40-60	N-P
Natural hard steel	30-40	J
Steel castings, large	16-20	G
Steel castings, small	20-24	G-H
Forged-steel shafts	24	H
Crucible steel	40	L
Tool steel, annealed	30-36	I
Tool steel (facing)	30	H
Tools (wet grinding)	24-36	H-I
Tools (dry grinding)	30-40	I-J
Pinions	30-50	M

4

(*d*) *Hardness of the Abrasive Material.*

Even more important for the grinding capacity of the disc than the size of the grains is the hardness of the latter, which naturally corresponds in all cases to the natural hardness of the abrasive. The best of all grinding discs would be composed of diamonds, held together by a suitable binding medium; but this, unfortunately, is impracticable on account of the heavy cost, and will probably continue to be so. Next to the diamond in hardness comes Acheson's carborundum; but against this material is the circumstance that it crystallizes in flat crystals, which greatly reduce the porosity of the disc, and thus preclude its application to the grinding of fine, soft materials, such as copper, cast brass, etc., owing to the liability to smear. Even for coarse materials, such as grey cast iron, these carborundum discs are unsuitable, unless the material is very rough and burred or finned, so that it keeps the grinding surface of the disc always rough.

Of course, carborundum discs can be used if they are run at such a speed that no smearing can occur; and in such cases a larger amount of work can be got through than with any other grinding wheels. Unfortunately, however, the wear of the discs is proportionately increased and the relative economy of this abrasive is again called in question. Of course, this objection disappears when output is of more consequence than wear, that is to say, when time-saving is the predominant factor.

Thus, for instance, carborundum discs will grind chill-cast shafts much faster than other abrasives, since, according to Lebert, a chill-cast shaft of best and hardest quality, measuring 40 × 12 inches can be ground down by 1½ to 2 inches in an

hour by means of a 20 × 6-inch disc, running at 1350 revolutions, the shaft itself being rotated at a speed of 42 revolutions, and advanced at the rate of 20 inches.

The grains of the abrasive must not be brittle. The importance of this will become evident at once if we consider the various stages through which the grinding surface of the disc has to pass. The surface of the disc must present at all times a number of projecting crystals which wear down in proportion to their hardness, until they have been reduced to the same level as a further number of crystals which have been hitherto embedded within the disc; and it is only when these latter crystals begin to exert an abrasive action that the worn crystals should drop out. If, however, the crystals are brittle, they will not wear down, but will break off before their full task has been completed, the grinding surface then becoming pitted and rapidly wearing away.

This also demonstrates the importance to be attached to the hardness of the binding medium as well; because, if this be too brittle and too resistant—as may well happen in the case of chemically-combined media—the worn-out grains cannot get loose from the binding medium, and the disc begins to smear. Furthermore, since there is no possibility of adjusting the hardness of these discs with chemically-combined media in the course of manufacture, they can never fully replace sandstone, and must be restricted to a comparatively narrow sphere of applicability, namely, to rough grinding, for which work, however, they are well adapted.

The case is different with ceramic discs, in which the hardness of the binding medium can be graduated to a nicety. This property has enabled the ceramic discs—which, in addition to being admirably adapted for fine grinding (and given

a sharp-edged abrasive material and a properly selected hardness of the binding medium), will grind steel just as well as sandstone and without causing the work to run hot—to drive sandstone entirely out of the field.

The main object in view in all the operations going to produce artificial grindstones is, therefore, to perfect the grinding capacity in the two chief points already mentioned, namely, the hardness of the abrasive and the binding medium. Some of the modern processes for this purpose will now be described.

The firm of Simons & Co., Soest (Westphalia), has taken out a German Patent (No. 85, 953) for a process of making emery-stones with a magnesite binding medium. The feature of the process is that the pulpy mixture of magnesium-chloride solution, magnesite and emery powder is placed in metal moulds, which are mounted on a jig table, the vibration of which causes the specifically heaviest portions of the mixture, viz. the grains of emery, to settle down gradually to the bottom of the mould as compactly as possible, each grain having time to assume the most suitable position with regard to its neighbours. This process gives an emery-stone consisting of 90 per cent of emery and only 10 per cent of magnesite binding medium, the superfluous portions of the latter being forced upward by the jumping movement of the table, and then easily removed. Hitherto, such superfluous portions of binding medium have merely contributed to the weathering of the stones; but, in the new process, the smallest possible amount is left in, and merely fills up the spaces between the compactly arranged and resistant particles of the abrasive.

Another process, that of F. H. Paul, Bredstedt (Schleswig)

—German Patent, No. 168,443—incorporates 10 to 50 per cent of fine pumice powder with the abrasive material, in order to impart to the resulting mass such a texture that coarse-grained emery will exert merely a gentle abrasive action, whilst fine-grained emery is protected from smearing. In this case an attempt is made to obviate defects arising from the grinding material being too compact or the reverse; for, when the grain of the abrasive is too fine and the mass too compact, it soon fills up and becomes smeary, so that it no longer bites properly; whilst, if the grain be too coarse and the texture too loose, the grinding action is excessive and at the same time the rate of wear is accelerated.

A similar purpose, namely to obtain a grindstone with a rough, porous surface, underlies the process of F. Swety, Marburg (Austria)—German Patent, No. 169,735—in which the mixture of abrasive and binding material is treated to an addition of pulverized crystalline material, capable of extreme subdivision, so that it breaks or splits off in small fragments from the surface of the stone when in use, and thus leaves the surface always rough and porous. The material added for this purpose consists preferably of mica, usually micaceous iron ore.

(*e*) *The Manufacture of Emery Discs, etc.*

The preparation and treatment of emery, up to the stage of making the mixtures for the manufacture of emery discs, has already been described. From that point onward, the manufacturing process depends on the binding medium selected; and in this connexion a large number of fundamentally different methods have arisen, which are not of sufficient interest to discuss in detail, more especially since the makers

concerned adhere to their own methods, which they do not wish to make public.

The discs may be moulded either by hand or in moulding machines.

According to information supplied by S. Oppenheim & Co. and Schlesinger & Co., emery and machinery manufacturers, Hainholz (Hanover), the Atlas emery discs produced in their works are made with a binding medium of rubber.

The proportions of the mixture are arranged to furnish discs with a tough and elastic structure. The moulded discs are then subjected to pressures up to 3500 tons in a large hydraulic press (Fig. 10), and dried. After the drying process they are turned down in the lathe (Fig. 11), by the aid of bortz (black diamond) cutters. A specimen of these diamonds, weighing 750½ carats and worth £6000, is shown in Fig. 12.

These Atlas discs are used for dry and wet grinding. Another mark, the Vulcan disc, suitable only for dry grinding, is made in the same way.

On the other hand, the Helios discs of the same makers have a ceramic binding medium, and are fired in saggers in a pottery kiln for several weeks. These baked discs are extremely hard and porous, and may be used for wet and dry grinding.

Fig. 13 shows the doorway into the kiln, with the discs piled up in columns.

The discs (Fig. 14) on issuing from the kiln, are placed in a well-ventilated, but dry store, where they are made ready for sending out.

An extremely interesting process is the manufacture of emery cloth, which was formerly made by hand, until, early

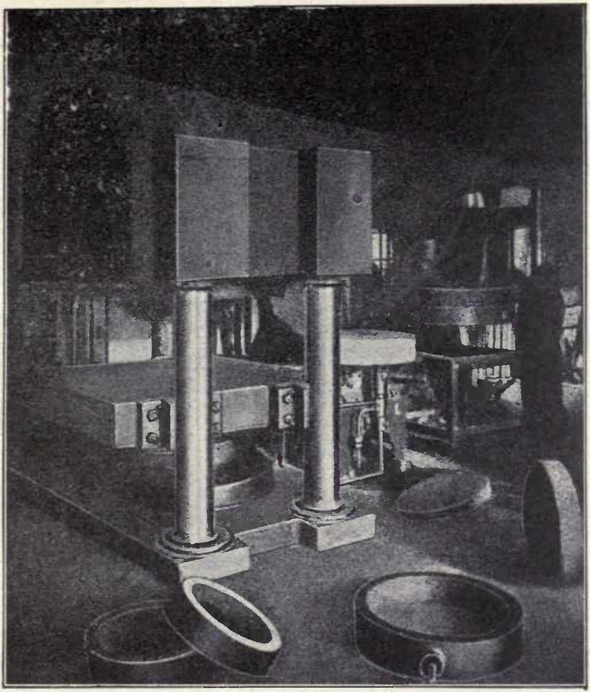

FIG. 10.—Hydraulic Press.

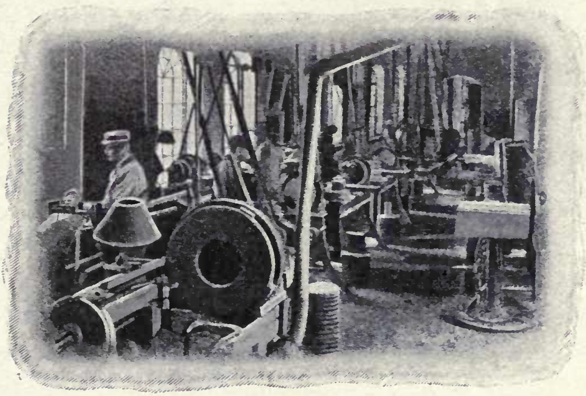

FIG. 11.—Turning Discs in the Lathe.

in the "seventies," the present manager of the Hainholz works devised a highly ingenious machine, enabling the whole

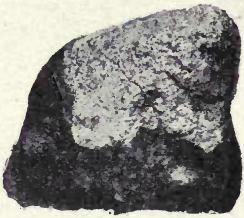

Fig. 12.—Diamond.

Fig. 13.—Glimpse of the Interior of a Kiln for Baking Emery Discs.

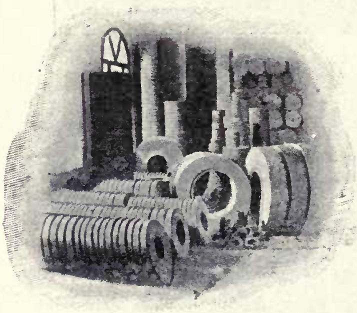

Fig. 14.—Emery Discs, Ready for Dispatch.

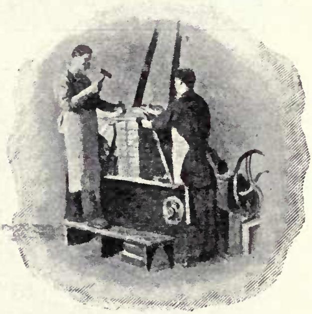

Fig. 15.—Packing Press.

process to be carried out by mechanical means. The machines are f d with rolls of the fabric or paper to be coated

with emery, apply a strong coating of glue to the one side, and then convey the material to an apparatus which strews a layer of emery powder of the desired grade over the freshly glued surface, uniformity of distribution being ensured by special and highly ingenious devices. A point to which special care is directed is that the apices of the sharp-edged emery grains shall point upward, so as to intensify the abrasive action. In this way a material that is particularly suitable for rubbing down wood is obtained.

The paper or cloth is next dried in exhaust-driers, and when perfectly dry is cut, by a machine, into sheets, which are tied together in bundles of twenty-four to twenty-five by female labour. This machine is equipped with a printing attachment, which stamps each sheet and puts the trade-mark on it. The bundles are baled in a packing press (Fig. 15), and are dispatched in that condition. Fig. 16 gives a view inside an emery-cloth factory. The manufacture of glass-paper and sandpaper is carried on in the same way, and can be advantageously combined with the production of emery cloth.

(*f*) *Varieties and Shapes of Emery Discs, Wheels, and Cylinders.*

Grinding discs, etc., may be classified in the first place according to the abrasives of which they are composed: Naxos emery, corundum, Canadian corundum, carbonite (carborundum), diamantino, and electrite discs.

Another classification is based on the purpose for which the discs, etc., are intended: wet or dry grinding, or both.

With regard to the shape of the discs, this varies to an extraordinary extent, with the idea of suiting different classes of work, so that a detailed description is impossible, each

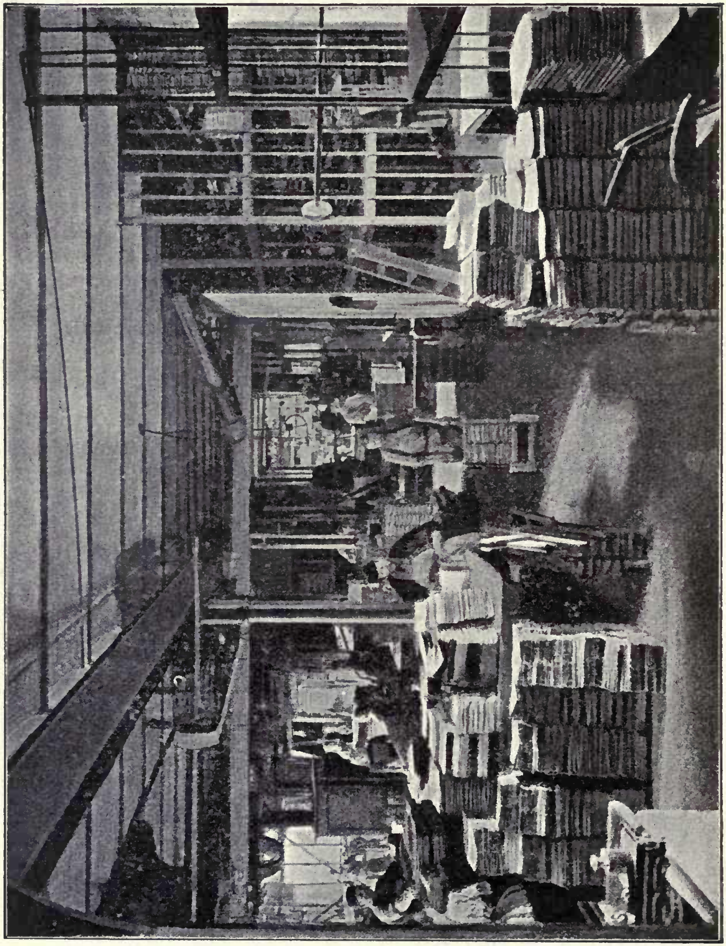

Fig. 16.—Room in Emery-cloth Factory.

maker producing a very large number of shapes, sometimes running into hundreds.

Nevertheless, mention will be made of a few characteristic shapes, such for example as the peripheral sections of discs for sharpening saws, typical shapes of which are shown in Fig. 17. Another characteristic shape (Fig. 18) is that of the discs for sharpening the slicing knives used in sugar factories, the thickness and bevel requiring to correspond accurately to the shape of the knife.

FIG. 17.—Peripheral Sections of Discs for Sharpening Saws.

FIG. 18.—Peripheral Shape of Disc for Sharpening Slicers.

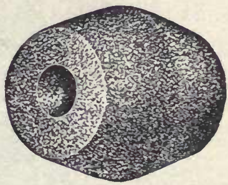

FIG. 19.—Emery Roller

Interesting shapes are presented by the emery rollers intended for sharpening the blades of mowing machines, the periphery having to correspond in shape to that of the blade. Emery cylinders are also made in various sizes to fit the grinding machines employed for producing flat surfaces, and also for grinding the broad cutters of machines for splitting paper and leather.

A special type of grinding wheel is the segmental pattern, illustrated in Fig. 20, the peculiar feature of which is that the grinding surface is composed of a number of separate blocks with intermediate spaces. The advantage of this form is that it runs cooler in working, mainly because the gaps allow increased access of water to the work. Consequently, there is

less risk of the work or the grinder getting hot—a matter of special importance in grinding hardened steel. Segmental grinders are also less liable to become smeary, and retain their abrasive power more fully. They are, however, only advisable for use in very rough work, and particularly in cases where large quantities of material have to be ground away quickly. Nevertheless, they may also be used for heavy work

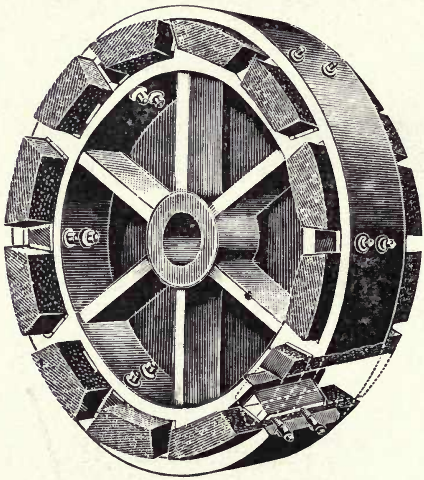

Fig. 20.—Segmental Grinding Wheel.

on very tough material, such as armour plates, or for grinding the cutters of large, heavy plate shears, and hollow-ground, wood-planing cutters.

(g) *Experiments on the Stability and Capacity of Emery Wheels.*

Prof. M. Grübler, of Dresden, carried out a number of experiments to determine the tensile strength of emery and carborundum discs, the Committee of the Association of German

Engineers having expressed a desire for such trials—and provided the funds for same—with a view to ascertaining the peripheral velocity at which grindstones can safely be run. Trials were made with grinding wheels 20 inches in diameter, 2 inches wide, and 2 to $3\frac{1}{2}$ inches bore, fifty-four emery discs and three carborundum discs having been placed at disposal by ten German and American firms.

The tensile strength was generally greatest in the wheels made with vegetable binding media, the maximum strength (287 atmospheres) being furnished by a wheel supplied by the Naxos Union, Frankfurt-on-Main. The great differences prevailing among the various makes, however, may be gathered from the fact that the vegetable-bound product of another maker had a tensile value of only 134·3 atmospheres.

Among the emery-stones, made with ceramic binding medium and fired at white heat, a German make again gave the highest tensile value, namely 137·2 atmospheres, whilst the American products of similar character gave a value of only 97·4 atmospheres.

In point of working efficiency, grinding in modern emery grinding machines is far superior to the older methods of working. According to a report by Ludwig Loewe & Co., Berlin, the time required for rough turning a shaft $2\frac{1}{4}$ inches in diameter and 14 inches in length, on a lathe, and then grinding it in a Norton grinder, from an initial thickness of $2\frac{1}{2}$ inches, is only thirty-eight minutes in all, the finished work being true to within $\frac{1}{2500}$th of an inch. With the older method of roughing and finishing in the lathe, forty-eight minutes would be necessary. It must also be remembered, in order to make a proper comparison, that the lathe-finished work had afterwards to be filed down, an operation the duration and result of which depended to a large extent on the skill of the work-

man, and was capable of influencing the quality of the product considerably.

In the course of time, moreover, the working capacity of grinding machines has been greatly improved. Thus Lebert states that whilst formerly the removal of half a cubic inch per minute was regarded as good work with a circular-grinding machine, the capacity of these machines has now been doubled, and at present three-quarters of a cubic inch is looked upon as an exceptionally small quantity to grind off in that time. The motive power has also been reduced from 12 h.p. to about 7 or 8 h.p., owing chiefly to the superior quality of the abrasive materials used.

(*h*) *Points on the Use of Grinding Discs.*

If a disc smears, this is generally due to excessive hardness; but if it neither smears nor bites, the fault is in the contrary direction, the disc being too soft.

Excessively rapid wear may be due to various causes, for instance:—

(1) to the disc being insufficiently hard;

(2) to the grain being too fine, in conjunction with deficient hardness, this being indicated by imperfect grinding;

(3) to the work being pressed too heavily against the disc; and finally,

(4) to the disc being too hard, a condition leading to rapid wear in consequence of the continued roughing of the disc.

The hardness of the disc must be selected in accordance with the size and weight of the tools to be ground. In order to grind hard articles as finely as soft ones, a coarser grinding disc must be used for the former than for the latter.

The selection of a suitable grinding disc is, even nowadays, rendered difficult by the circumstance that the different

makers have not yet been able to agree on a uniform system of marking to indicate the grain and hardness of their products. Such an agreement is highly desirable in the interests of the machinery industry and for the well-merited reputation of the grinding-machine industry.

A word in conclusion, on the use of grinding discs :—

It is true that the grinding discs of the present day will cut freely, so that it is superfluous to press particularly on the tools when grinding. For interior grinding, which is best done by the dry method, the freely cutting tool forms the ideal. Narrow discs should be selected for this purpose.

Bearing in mind the temperature of the work to be ground, wet grinding is preferable at the outset, in order to keep the work cool, though the risk of rusting should not be forgotten. The addition of lime or soda to the water, as a preventive of rust, however, may easily impair the grinding power of the disc, especially as it is the practice to use the greasy water over and over again.

2. The Further Treatment of Grinding Discs.

(*a*) *Mounting the Discs.*

Bearing in mind the extreme importance of mounting the grinding discs securely on the shaft, in view of safety in working, it is necessary to bestow the greatest care on this operation, because if keyed firmly on the shaft or driven on to a conical spindle, the brittle discs would crack at once. Hence, as they cannot be forced, it becomes a matter of principle to make the bore in the disc somewhat larger than the diameter of the spindle, and also a little wider than the opening in the flanged connexion pieces. This has also become a fixed practice, the first makers to examine the question thoroughly being the Naxos Union Co., Frankfurt-on-Main.

After long and exhaustive experiments they found that, in order to fix the discs firmly, they must be held, not by the whole inner surface of the flanges but only for a certain distance from the outer edge of same. The hold obtained by this method of mounting is quite sufficient to stand the highest strain required, and also obviates the various inconveniences arising in the case of smooth flanges.

The recognition of this fact resulted in the invention of the Naxos Union safety flange (Fig. 21), which is still used by

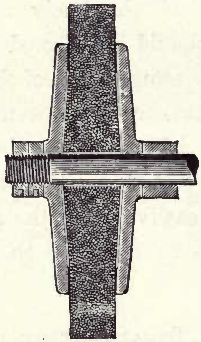

Fig. 21.—Safety Flanges.

the makers in question. Where possible, the grinding wheels are thickened at the centre, but not to such an extent as to fill up the recess in the flange and allow the surfaces to come into contact. If such a disc bursts, through careless or unskilful handling, the fragments will be retained in the mount in consequence of the thickened centre. Moreover, in order to utilize the disc fully as it wears away, all that is necessary is to replace the large flanges by smaller ones.

In some cases the flanges are also made of taper cross section (according to the Bernard system), though the conicity of the disc itself need not extend as far as the periphery, but

only for about two-thirds of the total diameter, the external portion being of uniform thickness.

Another very practical form of mounting is the Naxos system of using an iron core for discs with an elastic binding medium (Fig. 22), which core can be used over again when the disc is worn out.

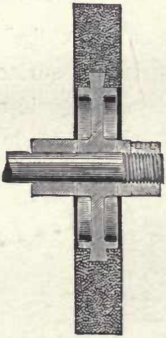

FIG. 22.—Grinding Disc on Iron Core.

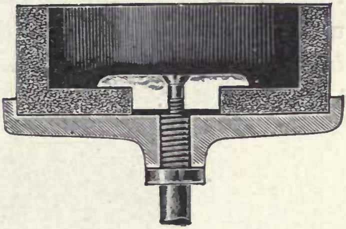

FIG. 23.—Ring Mount.

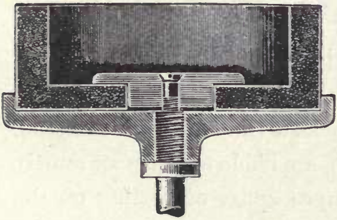

FIG. 24.—Grinding-cylinder Mount.

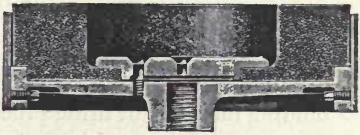

FIG. 25.—Grinding-cylinder Mount.

Figs. 23, 24, and 25 illustrate regulation mounts for grinding rings and cylinders, as made by the Schönherr emery works, Chemnitz. Here also the discs are merely clamped between a fast flange and a loose one, with the interposition of suitable rubber washers.

A ring mount is shown in Fig. 23, whilst Figs. 24 and 25

represent the method of mounting grinding cylinders. It should be noted that the iron guard ring in Fig. 25 is adapted to slide in grooves, so that it can be adjusted as the grinding cylinder wears down.

Other markets have elected to mount their grinding cylinders by means of a screwed-on flange, providing a guard ring in addition.

The Naxos Union also mount such emery cylinders and rings as are intended to be used on one lateral surface only, upon an iron plate (Fig. 26), to which a flange is securely fastened by screws (six in the case of wheels 16 inches or less in diameter).

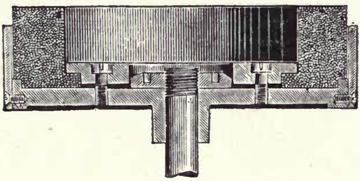

FIG. 26.—Iron-plate Mount.

(b) *Guards.*

It is evident that with the high speed at which these grinding wheels are run, any cracks arising from the material, binding medium, or firing process, are liable to cause extremely grave accidents, owing to the impossibility of putting on the brake at the moment such a wheel fractures or bursts; quite apart from the circumstance that the brake would be too late in operating, since the manifestation of centrifugal force in such cases is instantaneous. Though, so far as their action extends over the disc, the safety flanges exercise a certain protective effect, this protection has been found insufficient in practical working on the large scale. Consequently, better

guards, instantaneous in action, had to be devised, to protect both the grinder and his surroundings efficiently in the event of a disc breaking.

The idea was very soon evolved of encasing the grinding wheel and providing a protective hood, without unduly restricting the working surface of the disc. The Naxos Union were the pioneers in this direction, by inventing a guard that was capable of preventing the dispersion of a disc that broke while running, and of stopping the disc as quickly as possible.

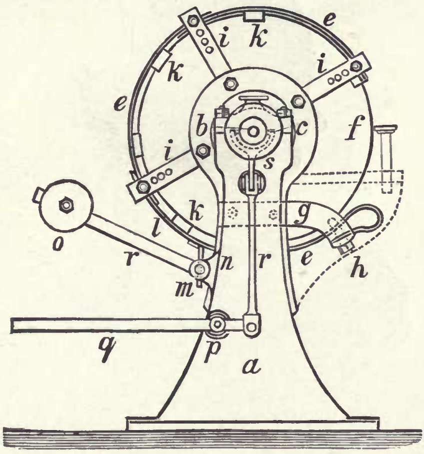

Fig. 27.—Lateral Elevation of Disc Guard.

The attainment of this purpose was sought by a form of construction, which is shown as a lateral elevation in Fig. 27, and as a rear view in Fig. 28, the latter giving an idea of the appearance of a disc equipped with the stop motion.

This device is constructed in conformity with the circumstance that the fragments of a disc that bursts while running are not detached immediately, but escape from the mount by degrees, until, when sufficiently released, they are projected

with great violence by the powerful centrifugal force due to the high peripheral velocity. (The device was patented, but the patent rights were abandoned by the inventors, in the public interest.)

A guard band *e* (Fig. 27), made in several parts, is mounted round the grinding disc *f*, being secured to a yoke *g* and forming a loop in front. This band is tightened by a clamp *h*,

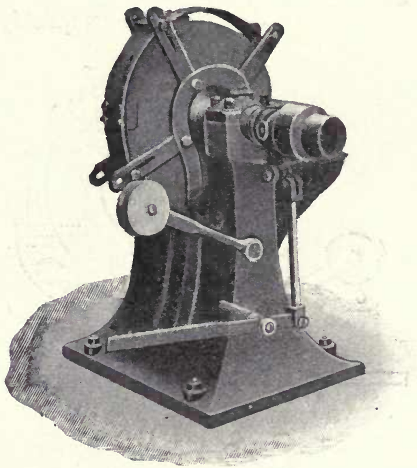

Fig. 28.—Naxos Union Grinding Machine with Protecting Guard. (Rear View.)

and is supported at a sufficient distance from the disc by arms *i* attached to the frame *a*. Brake cheeks *k* are arranged at different places on the band *e*. In the event of any broken fragments of the disc escaping from the mount, they are gripped by the brake cheeks *k* at a short distance from the periphery of the disc and, in consequence of the peculiar rotary arrangement of the supporting arms, are pressed with

increasing force against the disc until the latter is completely stopped.

Even should the detached fragment be merely small, it would and must come in contact with the brake cheeks, and thereby tighten up the guard band gradually.

Since this effect is produced very quickly with the high speed of running, there is a possibility of the band being torn

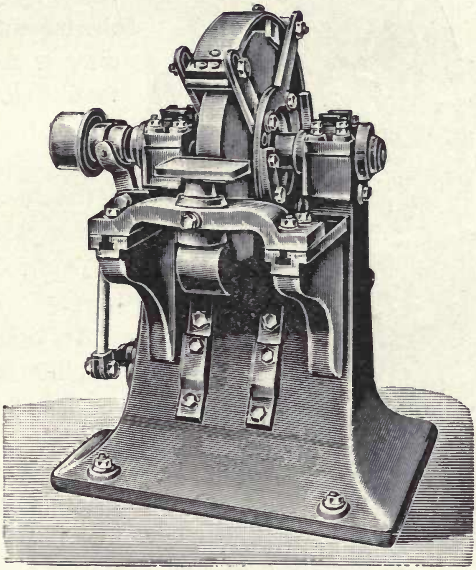

Fig. 29.—Front View Previous to Bursting.

loose in the case of large discs; so, to prevent this contingency, the band is tightened by an adjustable clamp *h*, and then, after a loop has been formed, is rigidly secured to the yoke *g*. Consequently, the braking action is prevented from being too brusque, the band having to be drawn gradually through

the clamp h, which effort absorbs a large proportion of the *vis viva* of the disc.

Furthermore, in order to neutralize as soon as possible the adverse effect of the pull of the driving belt on the braking action, the band e is fitted with a cam which, on the band being moved ever so slightly out of its original position on the bursting of the disc, is moved in the direction of rotation of the disc, by the braking action of the cheeks k. In this way, the pin n is deprived of its support, and the arm r, loaded by the weight o, falls on to the long lever arm q, whereby the clutch or friction coupling p is released, so that the belt pulley c runs loose on the shaft b.

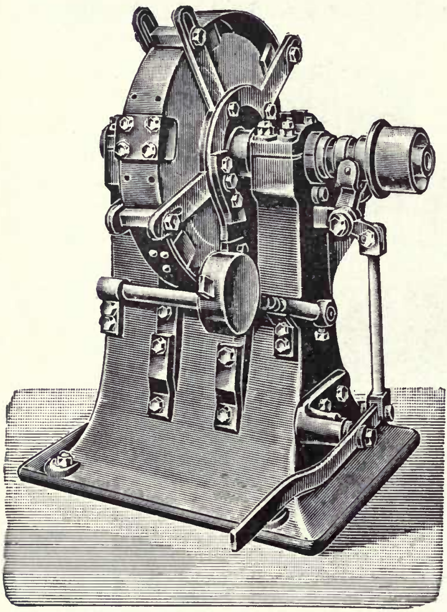

Fig. 30.—Rear View Previous to Bursting.

The manner in which this guard behaved under the official tests can be gathered from the table on p. 73 and the illustrations in Figs. 29 to 32.

Another guard device for grinding discs is the elastic, adjustable, and rotary hood, made of corrugated steel-wire gauze

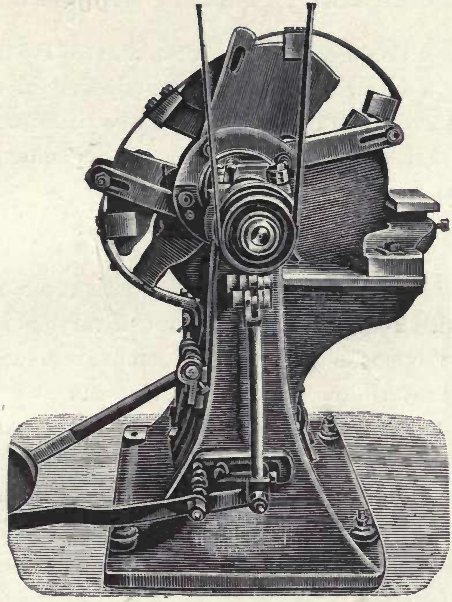

FIG. 31.—View after Bursting Test.

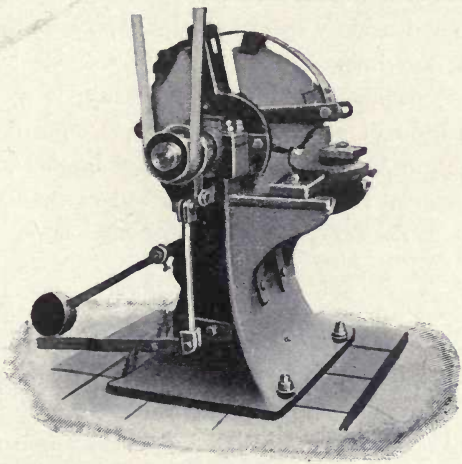

FIG. 32.—View after Bursting Test.

by Fontaine & Co., Bockenheim (Frankfurt). By tightening or loosening a screw, this hood can be adjusted in any position round the disc, so that grinding can be performed on any side : front, rear, above, or below, the operator being protected in every case.

Results of Bursting Tests

performed with emery discs 24 inches in diameter, $2\frac{1}{4}$ inches thick and with 2-inch bore. The discs, of varying degrees of fineness (see opposite page), were mounted in a grinding machine (Naxos Union, pattern AS), and run at a speed of n = about 1300 revolutions per minute, the peripheral velocity being c = about 132 feet per second.

A further advance in connexion with these adjustable guards is made by the new patents of the Naxos Union and of the Vereinigte Schmirgel & Maschinenfabriken A. G., Hainholz (Hanover).

That of the Naxos Union is a chain secured to rotatable, slotted arms and held by special clamps capable of tightening the chain at any link. In the other Co's. device, high-resisting power, combined with great elasticity, is secured by making the hood of several layers of superimposed strips of sheet metal, $\frac{1}{25}$ to $\frac{1}{18}$ of an inch thick. The additional advantage of easy adjustment is secured by the action of the strips and by the constant flexibility of these strips when superimposed.

(c) *Dust Exhaustors.*

It is well known that considerable amounts of dust, both coarse and extremely fine, are produced in grinding shops, which dust is very dangerous to the health of the work-people if inhaled. Consequently, attempts have long been made to

Test No.	No. of Minutes Run.	Impact Test, No. of Blows.	Result.	No. of Fragments Held by Guard.	Remarks on the Burst.	General.
No. 1. Fineness 6 n 1280 c 132 ft.	3	8	The bursting was accompanied by a dull noise, and the coupling loosened immediately, stopping the machine at once. Inspection showed that the guard hood (German Patent 119,529) had acted perfectly.	4	—	—
No. 2. Fineness 5 n 1280 c 132 ft.	3	6		4	A few small splinters weighing altogether about 4 oz. escaped from the hood.	—
No. 3. Fineness 11a n 1280 c 132 ft.	3	4		4	A small piece about 4 ins. long dropped vertically to the floor without any centrifugal force.	—
No. 4. Fineness 16 n 1280 c 132 ft.	5½	5		5	7 pieces, up to 2 ins. in size, fell direct on the floor, and 6 slipped out sideways; total weight about 6½ oz.	—
No. 5. Fineness 10 n 1280 c 132 ft.	3	11		4	The fragments that fell direct to the floor weighed 5 oz.	—
No. 6. Fineness 10 n 1280 c 132 ft.	9	9		4	After the 7th shock, the coupling released at once, without any injury being sustained by the disc. The machine was restarted and the test resumed with a powerful shock (No. 8). The 9th shock was delivered with such force as to break a bolt head, loosening the rail and allowing two large pieces of the disc to slip out, but without any centrifugal force.	The same hood had been used in tests 1 to 5, and not repaired in any way, except to pull it out straight each time. None of the bolt heads broke before the 6th test.
No. 7. Fineness 30 n 1625 c 167½ ft.	8	1		3	The disc burst explosively, with a powerful flame. Several pieces became detached from the three large fragments, and of these, 10 splinters, weighing 18 oz. in all, slipped out on to the floor.	—
No. 8. Fineness 19 n 1260 c 130 ft.	8	17		3	—	—

N.B.—These tests were carried out in the presence of officials of the Prussian Bavarian, Würtemberg, and Hessian Industrial-Inspection Departments, on 7 to 12 October, 1901.

find means for carrying off such dust in a safe and regular manner, in all occupations where this inconvenience arises. The matter is one of particular interest to the grinding industry, on account of the high-working capacity and speed of modern grinding machines; and has formed the object of careful investigation within the last ten years. The use of exhaustors naturally suggested itself, but the existing types were found unsuitable for this special purpose, and a variety of patterns have been evolved.

The Koerting injector is also suitable, provided the works are equipped with hydraulic mains (with a pressure of at least three atmospheres). Another highly practical device for drawing off and purifying dust-laden air from grinding machines has been introduced by the Naxos Union (German Patent, No. 126,473), no discharge pipe being required. Fig. 33 shows a grinding machine fitted with this attachment and adjustable, wrought-iron hoods with side walls of sheet metal. The dust before leaving the exhaustor, is intimately mixed with a fine spray of water by means of a small centrifugal pump, and is then delivered by a current of air into a chamber, specially provided in the base of the machine, where it is deposited, the air—which is now perfectly free from dust—being returned into the room. This device, which admirably fulfils its purpose, has the additional advantage of being continuous in action and requiring no special attention.

(*d*) *Roughing and Trueing the Grinding Discs.*

In course of time and in consequence of the uneven pressure in grinding by hand, even the best and hardest grinding discs get out of true, and the pores become clogged. The resulting unevenness and smoothness of the disc must be remedied by

trueing and roughing, that is to say by lathe turning and reboring.

As a rule, bortz is used for this purpose, a crystal being care-

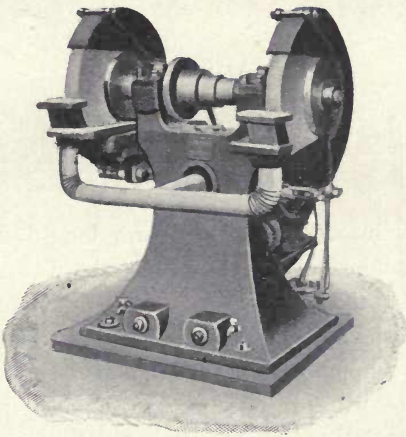

FIG. 33.—Naxos Union Dust Exhaustor. (Front View).

fully mounted in a steel holder and employed to turn down the disc in a lathe, either by the aid of a hand rest or slide rest. In this way the unevenness and smoothness of the disc can be removed in a few minutes.

CHAPTER III.

GRINDING MACHINES.

1. Introductory.

Although the machinery manufacturer long desired to have a grinding machine capable of replacing the file and the ordinary grindstone, and turning out more work than these, the importance of these new machines was slow to be recognized, and considerable scepticism was exhibited by machinery makers with regard to the offers and statements made by the makers of grinding machines. It was only as a result of exhibitions that the two parties eventually arrived at a mutual understanding, and the manufacturing engineer learned to appreciate the new branch of machine-tool construction. The first Düsseldorf Exhibition afforded this opportunity, and also yielded practical fruit in so far that, since then, the indispensibility of the grinding machine has been admitted for the workshop, fettling shop, and tool grindery. And in the thirty years which have elapsed since that Exhibition, the grinding machine has made its way into all branches of the machinery industry, so as to be now recognized as an essential part of the equipment of even the smallest shops.

The increasing requirements of that industry, under the growing pressure of world competition, and especially through the necessity of making greater use of hardened machine parts

that cannot be worked in the lathe or the planing machine, but require to be ground by the aid of emery or corundum discs, soon led to increased appreciation of the grinding machine.

The new tasks included the grinding of slide rods, the construction of machines for flat and circular grinding, to work chill-cast and porcelain rollers perfectly true for the purposes of the iron, papermaking, milling, and clay industries ; the construction of machines for sharpening saws and cutter blades, as also machines for special purposes, such as finishing the inner surfaces of bushes, valve-links, cast-iron of vessels, etc. In a word, the metal and machinery industries seemed all at once to concentrate the whole of their wishes and requirements on the grinding-machine industry, with the result that the makers were so overburdened with orders that a regular inventional boom set in. Then, after these years of storm and stress, came the period of quiescence and reflection, affording ample opportunity for weighing up the results achieved, and giving the representatives of the industry in all lands occasion for testing the devices most likely to be of practical utility, and to derive fresh incentives from the requirements of practice.

In this way the grinding-machine industry has grown and developed to such an extent that, nowadays, planing and drilling machines, and even lathes are mostly used for roughing-out work, the finishing being effected by methods of grinding that ensure a high degree of accuracy.

Within the limits of a technical sketch it is naturally impossible to give a complete picture of an industry that has developed in so many ways and directions, and has to some extent become more or less interwoven with all other industries and the machines used therein.

It will probably, therefore, be sufficient to deal with a few

of the main branches of this industry, as is done in the following section.

2. Principal Types of Grinding Machines.

(a) *Tool-grinding Machines.*

The grinding machine for grinding tools is the original form, which was only later succeeded by the manifold applications of the grinding machine as an up-to-date working machine. The prime essential for doing good work is a sharp tool; and this condition must be maintained by frequent grinding in order to retain the working capacity of the tool itself. Formerly, this operation was performed on an ordinary grindstone, but is now carried out by means of tool-grinding machines, the simplest forms of which are used on cutting tools, such as drills, chisels, planing tools, lathe tools, etc., and are particularly valuable in all shops where the turners or planers have to sharpen and set their own tools.

These machines are very strongly built, the shaft being of best steel and ground true to fit the bearings, which are of red brass, fitted with ring lubricators and bolted on to the top of the frame. It being very important that the hardness of the ground tools should not be impaired, dry grinding is out of the question, and all these machines are, therefore, fitted with water-feed. In the newest patterns the top of the frame is dished to form a water-trough, the water being fed automatically by a centrifugal pump from the water-tank inside the hollow frame. The dirty water drains back into the tank, and after depositing the contained solid matter is used over again. For small shops machines of this type are also supplied with a support or with a wall-bracket, the water being supplied by means of a dropper mounted above the machine.

This is the primitive form, corresponding to the method used with ordinary grindstones.

For grinding heavy lathe and planing tools, up to 3 inches

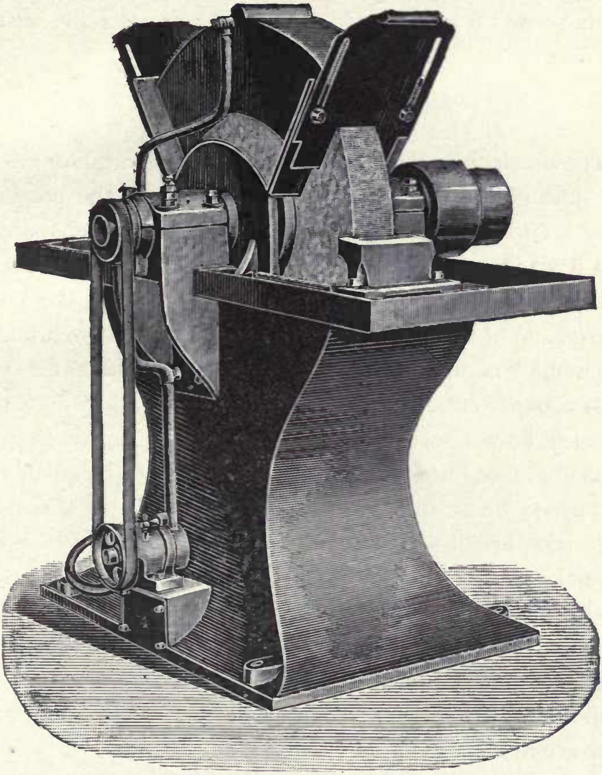

Fig. 34.—Machine for Wet-grinding Tools.

square, a far stronger pattern of grinding machine is naturally required.

Fig 34 shows one of these very powerful machines, suit-

able for large works in which heavy planing and turning tools and chisels are used. This machine, which is made by the Schmirgelwerk Dr. Rudolf Schönherr, Furth, nr. Chemnitz (Saxony), may be fitted with an emery disc 40 inches in diameter and 6 inches wide, and weighs nearly a ton without the disc.

(*b*) *Knife-grinding Machines.*

These machines acquired considerable importance even at the time of their first introduction, owing to the possibility they afford of grinding blades with accuracy and dispatch, and it was a source of pleasure to be able to replace the old ordinary grindstone by the quicker grinding disc, the proper sharpening of machine knives being a matter of great interest in numerous industries. For example, cutters for wood planes, paper cutters, leather-splitting knives, drawing knives, tobacco knives, plate shears, cork cutters, sugar choppers rubber cutters, etc. etc., all of which have to be quickly resharpened when dull, accuracy of grinding being also essential. Some of them have to be ground flat, others hollow ground, this latter method being particularly needed for blades that have to cut cleanly and sharp (cork cutters, tobacco knives, and cutters for wood planes), whereas flat grinding is practised more in connexion with cutters that work with a shearing action and are subjected to heavy strain in use (paper cutters, plate shears, etc.).

According to the class of work to be done, the machine selected will be one in which a grinding cylinder or a disc is used. In the largest of these knife-grinding machines, used for grinding blades up to 13 feet in length and either flat or slightly hollowed, the blades under treatment are clamped

firmly in the machine, the grinding cylinder being moved toward the work. Figs. 35 and 36 show two special forms

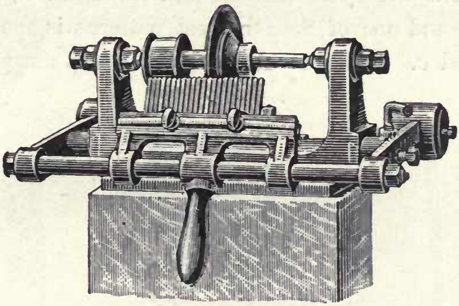

Fig. 35.—Machine for Grinding Slicer Blades.

of these machines, the first representing a machine for grinding slicer blades, and the second one for shaped blades.

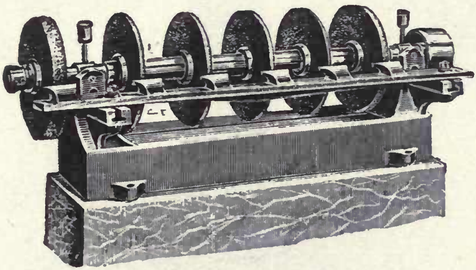

Fig. 36.—Machine for Grinding Shaped Blades.

(c) *Saw-sharpening Machines.*

Very great difficulty was formerly encountered in sharpening circular saws for wood and metal work, and also band-saws, but this has been completely obviated since the invention of automatic saw-sharpening machines, with straight

6

cut, and of automatic sharpening machines for circular saws for cutting metal. Special attention has been devoted to this class of machine by Fontaine & Co., Bockenheim, Frankfurt-on-Main; and one of their newest patterns is shown in Fig. 37A, B, and C. This machine automatically sharpens hot or

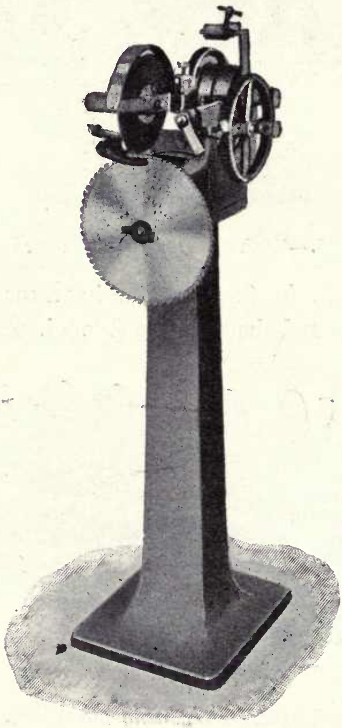

FIG. 37A.—Saw-sharpening Machine for Straight Cut, with Circular Saw.

cold saws up to 5 feet in diameter and $1\frac{1}{4}$ inch pitch. The clamping device with the circular saw to be sharpened can be easily and reliably raised by means of a threaded spindle.

One of the chief advantages of this type of saw-sharpening machine, however, consists in the fact that the emery disc is able to grind continuously, being uninterruptedly raised and

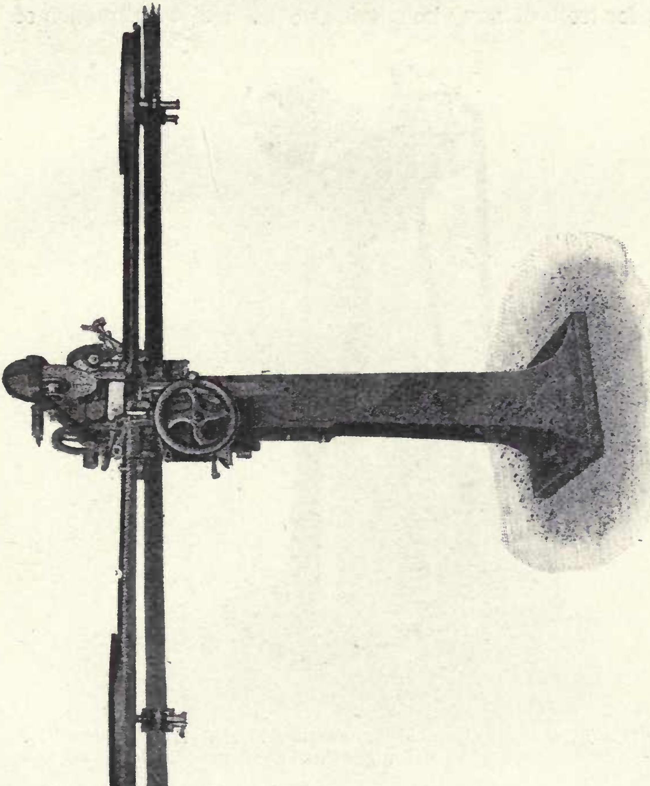

FIG. 37B.—Automatic Saw-sharpening Machine for Straight Cut, with Setting Device.

lowered to just the exact degree that corresponds to the height of the tooth to be ground. This does away with any dead traverse and ensures the maximum working capacity, since

the disc remains in contact with the tooth during the whole interval of time that is required for the rise and fall of the disc.

Another highly practical arrangement is that the feed of the saw, for teeth of any pitch and also the reciprocal motion of

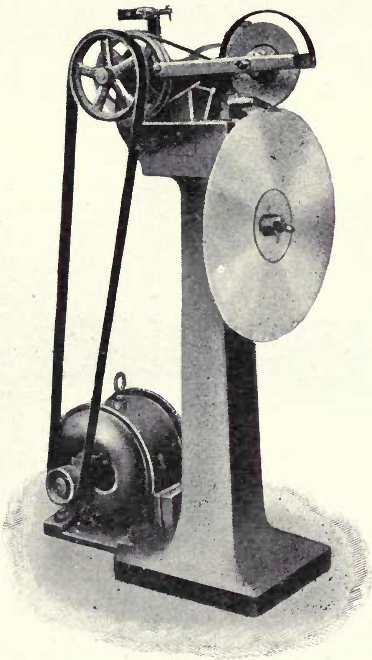

Fig. 37c.—Electrically Operated Automatic Saw-sharpening Machine for Straight Cut.

the grinding arm, can be adjusted by means of a single screw; whilst at the same time the movement of the grinding arm and disc can be adjusted independently. This device, of course, enables the machine to be adjusted very quickly for saws with teeth of different pitch; and again—also by means

of a single screw—the machine can be set for grinding band-saws with wide teeth.

(d) Machines for Grinding Flat Surfaces.

These machines are employed for grinding plane surfaces perfectly true, the work table being usually moved to and fro

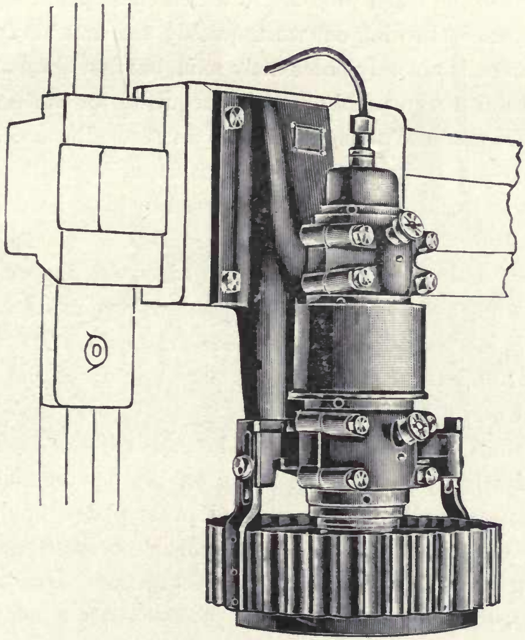

FIG. 38.—Grinding Head, with Central Water Feed, and Vertical Grinding Surfaces.

automatically in a straight line over a firm bed. Some of these precision machines will grind surfaces measuring up to $10\frac{1}{2} \times 4\frac{1}{4}$ feet, the free space under the grinding head being 6 feet wide and about 40 inches high.

A new pattern of this class of machine is shown in Fig. 38,

and is fitted with a head which has vertical grinding surfaces and central water feed. This head is mounted on a strong spindle of hardened, ground tool steel, and the powerfully driven grinding cylinder attacks the work by its vertical surface, a strong flow of water being provided.

Owing to the rapid pressure to which these grinding heads are exposed in turning out work quickly and accurately, their construction is not only necessarily solid, but first-class material and careful workmanship are also requisite for the bearings, which are made of phosphor-bronze and are adjustable. The weight of the spindle and head is taken up by ball bearings whilst the working pressure is absorbed by glass-hard, ground cast-steel pressure rings.

These grinding heads can be mounted on existing machines The grinding cylinders of the two patterns now made, measure $8\frac{1}{2} \times 3\frac{1}{8}$ inches and $14\frac{1}{2} \times 5$ inches respectively, the speed being 2200 and 1300 revolutions per minute and the driving power 4 and 8 h.p. respectively.

Machines have also been made that are intended to be slung, for the purpose of grinding off the fins on cast pipes, grinding and polishing hearth and press plates, anvils, safe plates, steel plate, etc.; as also grinding motors (Fig. 39) for working small surfaces of all kinds, removing inequalities and casting gates on machine parts. These latter machines are provided with flexible shafts, and as the motor can be connected up to any part of an electric lighting circuit, the machine can be used in any situation.

(*e*) *Special Types of Grinding Machine.*

The number of grinding machines for special purposes is naturally large in the extreme. For example, we now have

automatic machines for grinding out motor cylinders, thus saving the very troublesome labour hitherto necessary in finishing these off by hand. These machines enable such cylinders to be turned out perfectly true; and at the same time the pistons can be made of accurate dimensions from the start because the precise measurements of the cylinders are known, the grinding machine turning them out true to within $\frac{1}{2500}$th of an inch.

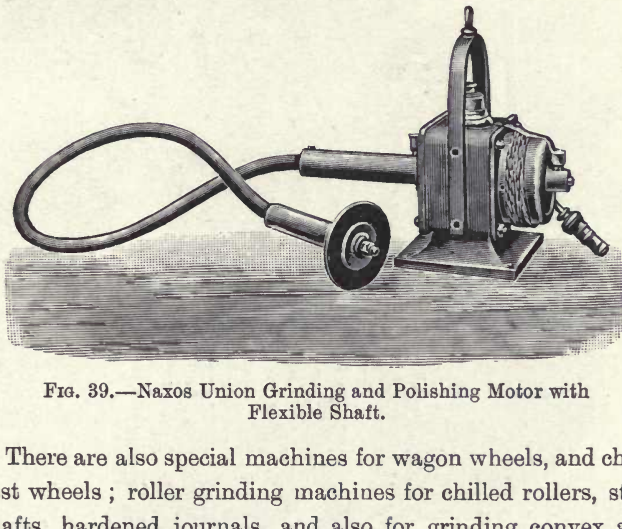

Fig. 39.—Naxos Union Grinding and Polishing Motor with Flexible Shaft.

There are also special machines for wagon wheels, and chill-cast wheels; roller grinding machines for chilled rollers, steel shafts, hardened journals, and also for grinding convex and plane surfaces on pulley rims.

Other grinding machines enable chilled rollers of the largest dimensions to be ground perfectly cylindrical, and with a handsome smooth surface, very quickly, whilst mounted in the mill housing. The grinding machine can be bolted on to the mill frame in a very simple manner, so that there is no need to take the rolls out or to use the expensive roll lathe. A

rolling mill equipped with one of these grinding machines (Fig. 40), is, therefore, able to dispense with spare rolls, the time occupied in grinding being so short as to reduce the inconvenience of stopping the mill to a minimum.

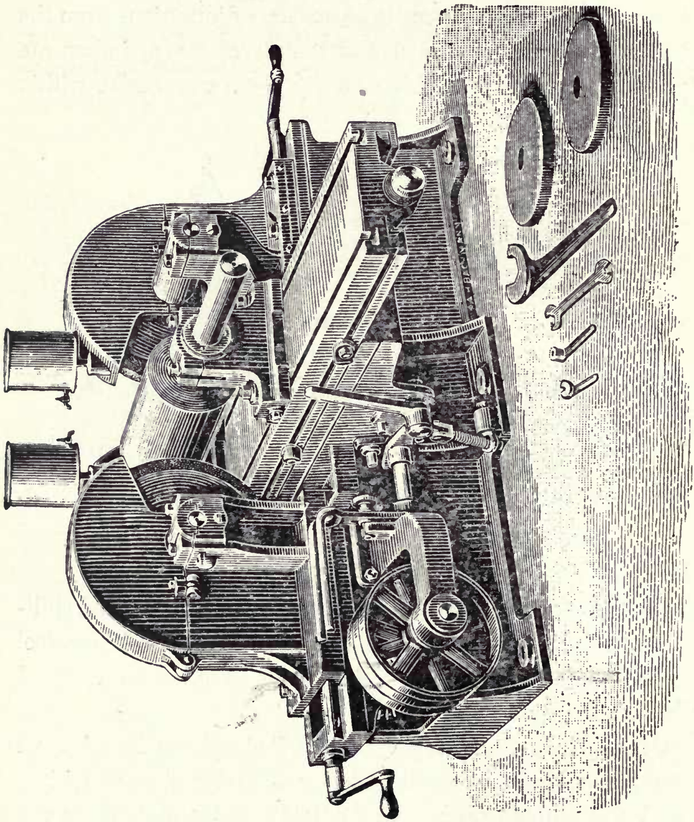

Fig. 40.—Naxos Union Machine for Grinding Chill Rolls.

Other special machines are made for grinding out rings and bushes; for trueing the bearing surfaces of plates, rings, and discs; for automatically polishing parts for circular stoves;

automatically finishing the teeth of cast pinions of any pitch and up to 20 inches in diameter; for automatically cutting wire nail cutters with curved or straight blades; for cutting through cranks and wire files, etc.

Finally, mention should be made of the unique automatic machine, "Cui," of the Naxos Union, for grinding twist drills as illustrated in Fig. 41. This machine will grind twist and

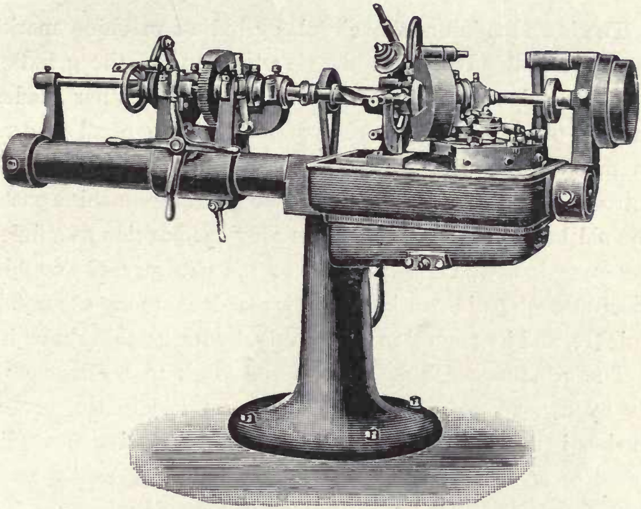

Fig. 41.—The "Cui" Automatic Machine for Grinding Twist Drills.

pointed drills up to 4 inches in diameter automatically and with the greatest accuracy. Water is fed to the work, and the drill is continuously rotated on its longitudinal axis, so that a perfectly centric cut is obtained, and no further finishing is required. The drill points are also ground without unchucking the drills, the operation being performed uniformly so as to leave the point perfectly central. In this way it is

impossible for the drill to bore holes larger than its own diameter.

The drills ground in this machine have the proper circular undercut, and are of high-working capacity. The machine requires little attention, so that even an unskilled operator can look after several at once.

3. Circular Grinding.

The introduction of the circular grinding machine marked an important advance in the development of the grinding-machine industry. It may be asserted that no other modern method of working has made such rapid and general headway in machine construction as this branch of grinding. The introduction of the universal circular grinding machine ousted the old lathe for all time from its previous position as a finishing machine, and relegated it to the category of roughing machines, since its work can now be done more accurately, quickly, and in general more cheaply, by the grinding machine.

The grinding machine enables the work to be finished to the exact size and according to pattern; and in the vertical models is specially adapted for accurately grinding out cylindrical or conical bushes, small motor cylinders, carriage-axle boxes, and capable of being successfully used wherever it is undesirable to suspend the work horizontally, whether on account of an unfavourable disposition of the load or of the inconvenience of an eccentric centre of gravity.

The circular grinding machine illustrated in Fig. 42 is capable of doing a great variety of work: grinding cylindrical and conical parts, such as spindles, bolts, shafts, etc. and also of grinding out bushes, bores, and rings. An adjustable steady is provided for slender work.

The automatic longitudinal travel of the table can be adjusted, by stops, in accordance with the length of the work in hand, the reversing being automatic. The vertical ad-

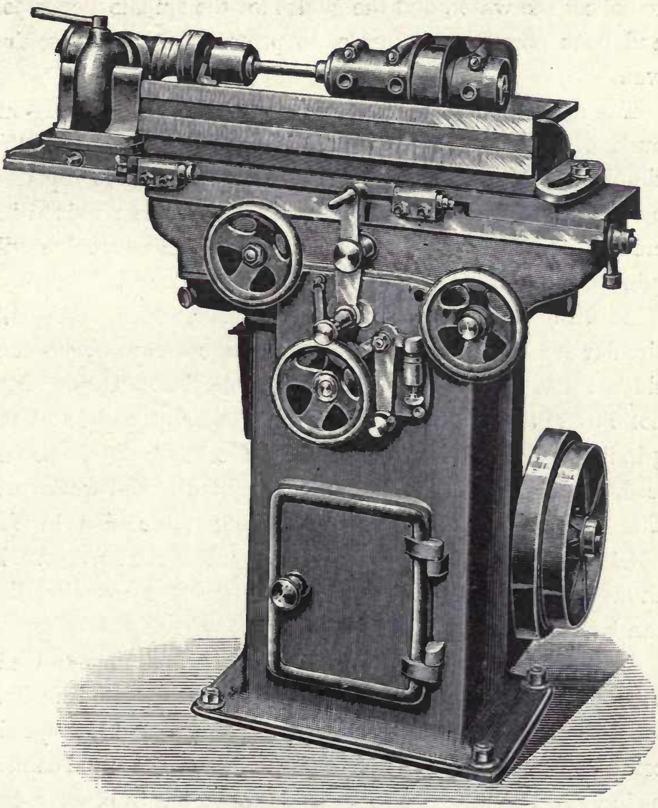

FIG. 42.—Naxos Union Automatic Circular Grinding Machine.

justment of the grinding spindle head can be effected either by hand or automatic mechanism. The rate of the automatic feed can be varied within wide limits and with the utmost nicety.

The table is divided for conical grinding, the upper portion being adapted to rotate through a graduated scale. A centrifugal pump is provided for wet grinding. The table is dished to collect the water, and the guides for the spindle headstock and back poppet are outside, to protect them from getting wet.

The figure shows the machine arranged for grinding-out bushes. For this work, as for inside grinding in general, the simple shaft in the grinding-spindle headstock is replaced by speeding-up mechanism, in order to give the requisite increased speed to the grinding spindle. This machine will grind work up to 14 inches long and 6 inches in diameter.

As with other automatic grinding machines, so also with circular grinders, a number of circumstances have to be considered that increase the difficulty of selection. These relate not only to the substance, shape, and other properties of the grinding discs, but also a number of other factors, such as feed, depth of cut, peripheral velocity of disc and work, etc. The experiments of Prof. G. Schlesinger (recorded in the "Zeitschrift des Vereines deutscher Ingenieure," 1907, p. 1227) showed how greatly the working capacity of a grinding disc can be influenced by these factors.

Lebert (id. 1908, No. 33) agreed with Schlesinger in advocating an increased peripheral velocity of the grinding disc, the difference in the working capacity at high and low speeds being remarkable. It is true that, at present, the speed cannot be increased as much as could be desired; but in practice the maximum available speed should be utilized to the full, no discs being used that will not stand being run at a velocity of 82 ft. per second. Lebert's experiments demonstrated that on increasing the velocity by 30 per cent the output was

raised two and three-quarter times, in three-quarters the time previously required.

4. Universal Tool-Grinding Machines.

The so-called universal tool-grinding machines also enjoy a great reputation in practice; for while it is a fundamental principle that grinding machines should be constructed solely for special purposes, the exceeding variety of existing tools has necessitated the introduction of a machine which, whilst the fundamental principle is retained, can be fitted for use for a number of special tasks, by the application of easily removable attachments.

In this way universal tool-grinding machines have been constructed, which can be supplied for accurately sharpening tools, milling cutters, and broaches of all kinds up to 8 inches in diameter and 24 inches long, these machines being equipped with numerous attachments, including the following:—

(1) A templet carrier for sharpening fluted, profile milling cutters.

(2) A circular apparatus for sharpening fluted, hollow, and ball milling cutters; with an attachment, mounted on the left-hand side of the machine, for holding circular cold saws up to 2 ft. in diameter.

(3) An attachment for inside and outside circular grinding.

(4) A universal divided for large spiral tooth milling cutters and reamers.

(5) An attachment for sharpening straight blades up to 2 ft. in length.

Similar machines, of stronger build, can also be supplied, for grinding tools up to 16 inches in diameter and 32 inches long; and it will be evident from the foregoing particulars

that such machines really deserve their name of "universal".

These machines, nevertheless, cannot deal with spreading machine-parts that are unsuited for being rotated. Such parts, however, are frequently met with, especially in locomotive shops, e.g. in grinding-out bushes, trueing journals, or facing sliding surfaces on valve-gear parts.

In general such spreading parts must be kept stationary, and, therefore, the grinding discs must be provided with a travelling motion as well as the rotary one. Consequently, such machines, must not only adjust the grinding disc, but must also impart an automatic travelling movement in any desired direction. The firm of Schmaltz, Offenbach-on-Main, has attempted to overcome these difficulties by the provision of a triple planet spindle, in accordance with the following principle :—

An inner spindle, running at high speed (4000 revolutions) and operating the grinding disc, is mounted eccentrically in a second spindle, which in turn is eccentrically and rotatably mounted in a third spindle. Both the outer spindles are run at a common, low speed. In setting the outer spindles, as shown in Fig. 43, the inner grinding spindle lies exactly in the centre of the whole. If, however, the outer spindles be turned in opposite directions—which may be done while the machine is running—the inner grinding spindle is displaced more and more from the centre, thus describing a planet motion whereby it is enabled to grind out hollow articles or grind down journals and bolts (Figs. 43B and 43C).

Fig. 43A shows the arrangement of the machine for grinding plane surfaces. The work travels, the grinding spindle simply rotates, with a slight axial up and down motion.

Fig. 43B shows the machine set for grinding out bushes, the work being stationary and the spindle describing planetary and axial movements.

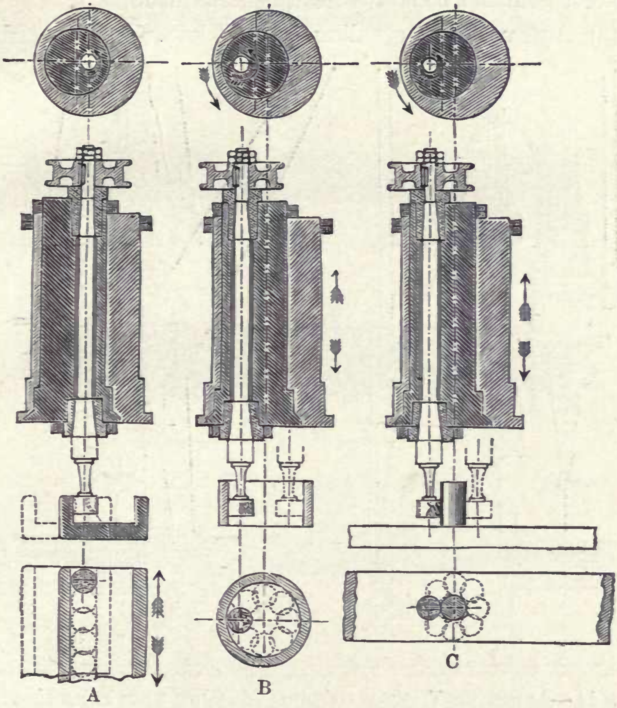

FIG. 43.—Sketch of Patent Triple Planet Spindle, Showing Arrangement and Method of Working.

Fig. 43C illustrates the grinding down of bolts. The work is fixed, the spindle moving with a planetary and axial motion.

For various reasons it is also advisable to equip these machines for vertical working as shown in Fig. 44, thus enabling the following operations to be performed :—

(1) Automatically grinding out hardened bushes, either loose or pressed into spreading machine-parts; and also grinding out fixed hollow cylinders of the kinds used in the construction of motors, pumps, locomotives, and general machinery.

(2) Automatically grinding down (close up to the edge)

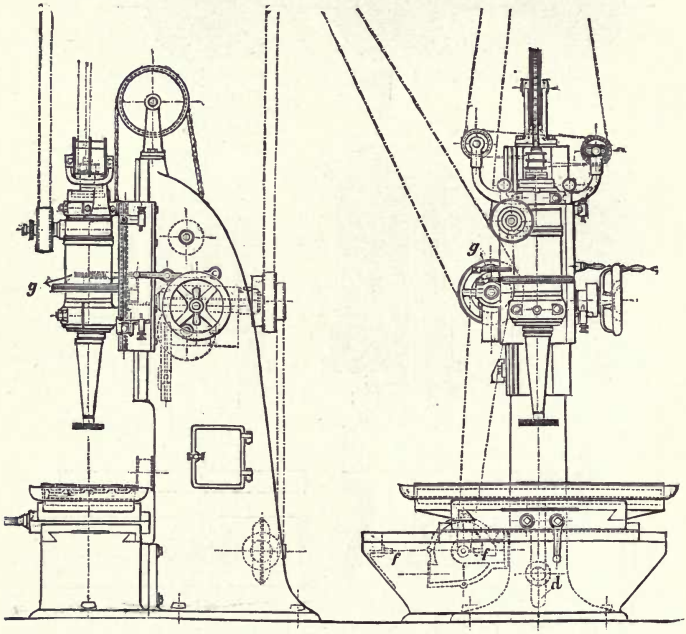

Fig. 44.—Automatic Vertical Grinding Machine with Patented Planet Grinding Spindle and Two-spindle Drive.

journals that are embedded in spreading machine-parts that cannot be rotated; also automatically grinding the outsides of piston-valve rings, and finishing slide-valve bushes on high-pressure locomotives. (These tasks are performed by another pattern of the same machine.) A third pattern enables all these different classes of work to be done.

5. Working Results Obtained in Practical Grinding.

Certain interesting results obtained in grinding practice by C. H. Norton, may be briefly summarized below.

The hardened steel shaft represented in Fig. 45A was not straight, and had to be ground down 0·015 inch. This task was completed in two and a half hours including the bearings.

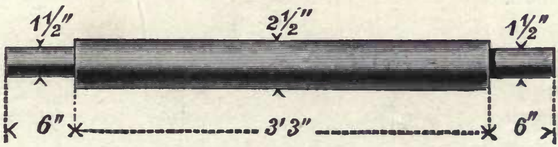

Fig. 45A—Hardened Steel Shaft.

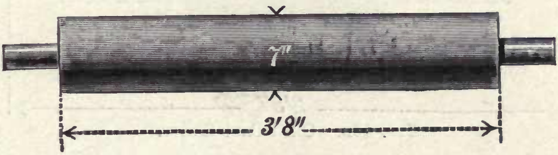

Fig. 45B.—Cast Iron Roller.

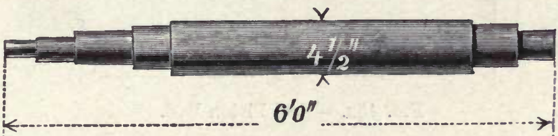

Fig. 45C.—Spindle of Engine Steel.

A cast iron roller (Fig 45B) measured 0·110 inch more on the ridges left by the lathe tool than the diameter required. It was ground down to a perfect cylinder in twenty minutes, all the marks left by the lathe tool being removed. After this the diameter had to be further reduced by 0·070 inch, which was accomplished in two hours, the whole time consumed in grinding the roller to exactly 7 inches diameter, being two hours and twenty minutes.

The spindle of engine steel, shown in Fig. 45C, was turned down roughly with a natural-hard steel tool, leaving an average of $\frac{5}{64}$ths of an inch to be removed by grinding. It should be pointed out that this spindle was 7 inches in diameter. The total time occupied in the grinding was two hours and twenty minutes; and the spindle was found true to within 0·001 inch.

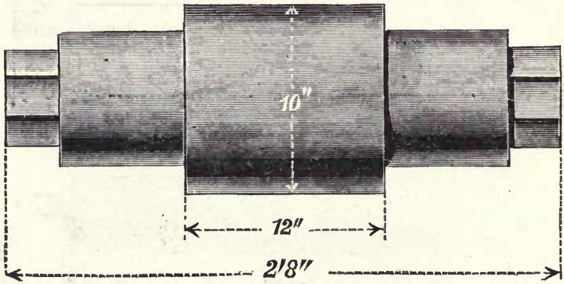

FIG. 45D.—Chill Cast Roller.

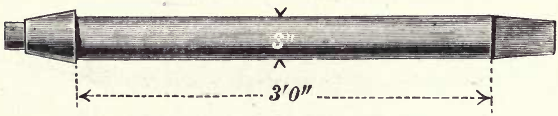

FIG. 45E.—Steel Piston Rod.

A chill-cast roller, 10 inches in diameter and 12 inches long (Fig. 45D), that had become worn in use, was ground in five minutes; whilst a similar roller, 10 inches in diameter and 24 inches long, though badly worn by having been used for grinding emery, was trued in one and a half hours.

Finally, a steel piston rod (Fig. 45E), the cylindrical portion of which had been turned down with a roughing tool, advancing $\frac{4}{5}$ths of an inch every 6 revolutions, was reduced $\frac{1}{32}$nd of an inch in diameter in twenty minutes, and was found to be

true to within $\frac{1}{2000}$th of an inch in length (3 feet), and to $\frac{1}{1000}$th of an inch in diameter.

In conclusion another instance may be cited of the wide sphere of application already possessed by the grinding disc, namely its extension to the stonecutting industry, in which the troublesome tasks of shaping with the chisel and then finishing by rubbing with sandstone, have now been replaced by the use of special grinding machines, which perform the work untiringly, with greater speed and accuracy.

THE END

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